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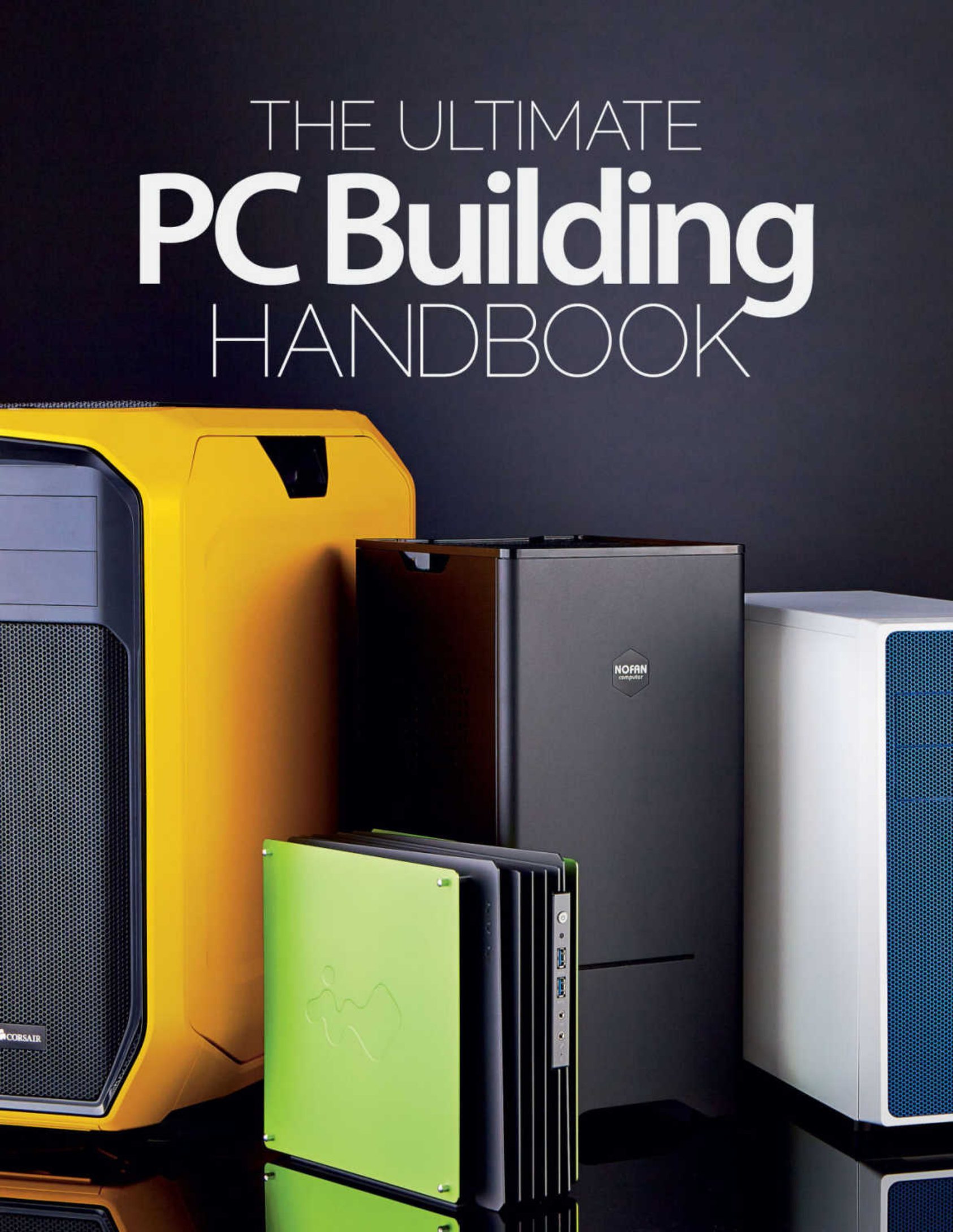

THE ULTIMATE PC Building HANDBOOK

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Welcome!

…to the only guide you need to understand the intricacies of building your own custom PC.

The PC market is unique in computing. You can keep your consoles and ready-made Macs, frankly: where they stay static and dull, PCs are fluid, every one individual, special, and imbued with the love and attention of its owner. The best PCs are hand-made, custom built to a budget or a dream, buffed and boosted to transform every possible unit of amperage into lurid pixels beyond the imagination of the PS4 and Xbox One. If your console isn't up to scratch, you can't exactly open it up and give it more pep. But a PC can give you more every month, if your budget allows. Upgrading can be incredibly addictive, as my bank manager will be all to quick to inform you.

This guide represents a hive mind of extensive knowledge from Future's techno-boffins across the globe, and I hope that it'll help you build or upgrade your perfect PC based on our advice and recommendations. Keep it handy, because you never know when you'll need it, and let us know at the address below if you've made something awesome.

And if you want a regular dose of PC hardware medicine, I can personally vouch for the guys at Maximum PC and PC Gamer magazines, whose love of – and devotion to – the noble goal of extreme PC performance knows no bounds. They literally never shut up about it.

Cheers, and best of luck with your build!

Alex Cox, Editor

The ULTIMATE HANDBOOK Manifesto

Ultimate Handbooks are designed to give you a complete guide to a device or piece of software you own. We aim to help you get more from the products you love and we guarantee you'll get the following from each book…

- A reference guide you can keep on your desk or next to your computer, and consult time and time again.
- New skills you can take with you through your life and apply at home or even in the workplace, whenever you need them.
- Expert advice to help you do more with your hardware and software – from solving new problems to discovering new things to try, we'll show you the best ways to do everything you might want.
- Clear recommendations for other products, accessories and services you can use with your device or software to get the best possible results.
- Advice you can take everywhere with you – thanks to the free digital edition of this book which you can download and read on your tablet, smartphone or laptop. See page 178 for more details.

How are we doing? Email **techbookseditor@futurenet.com** and let us know if we've lived up to our promises!

THE ULTIMATE PC Building HANDBOOK

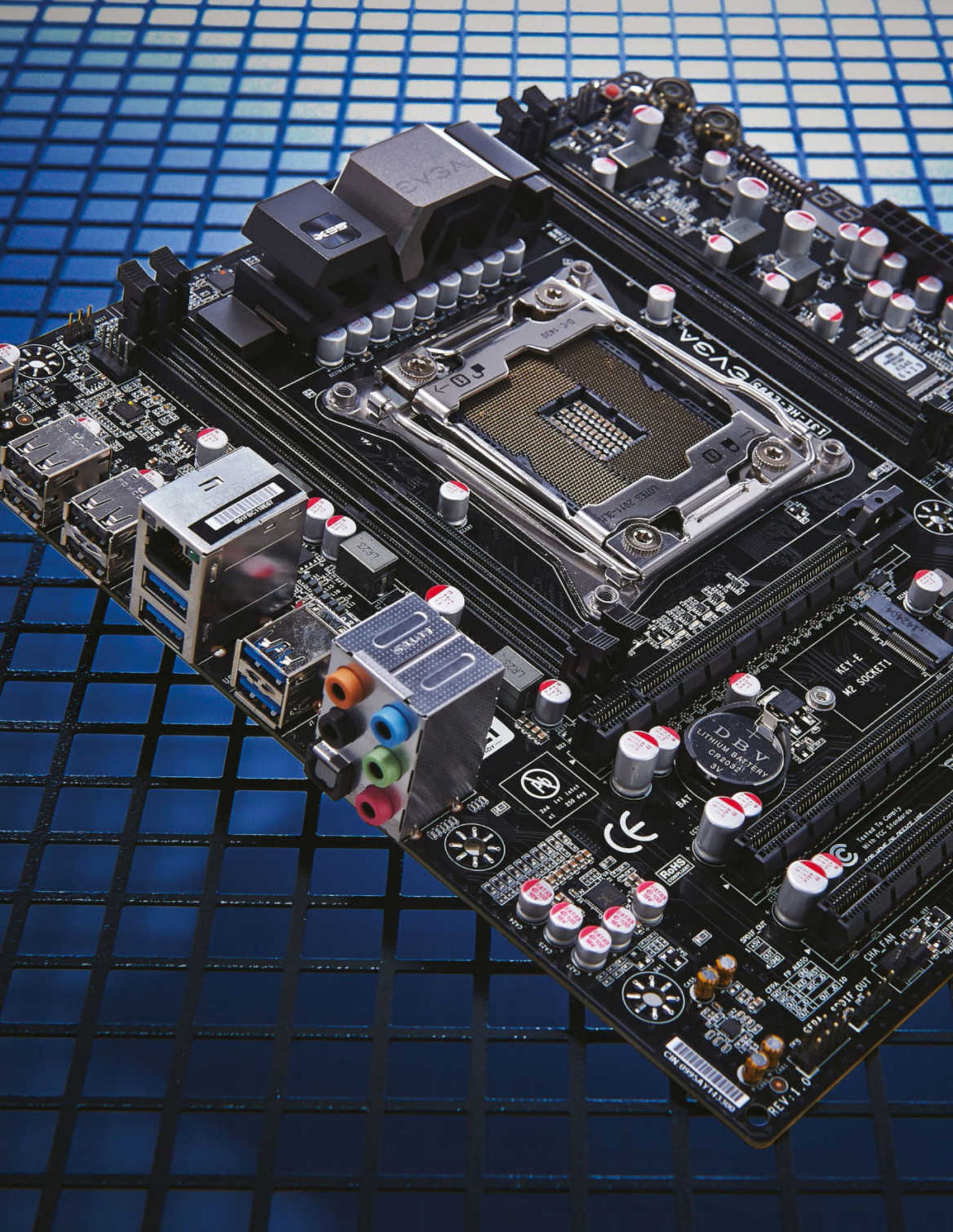
ESSENTIALS

CORE GEAR

KILLER COMPONENTS

THE BUILDS

TOP TIPS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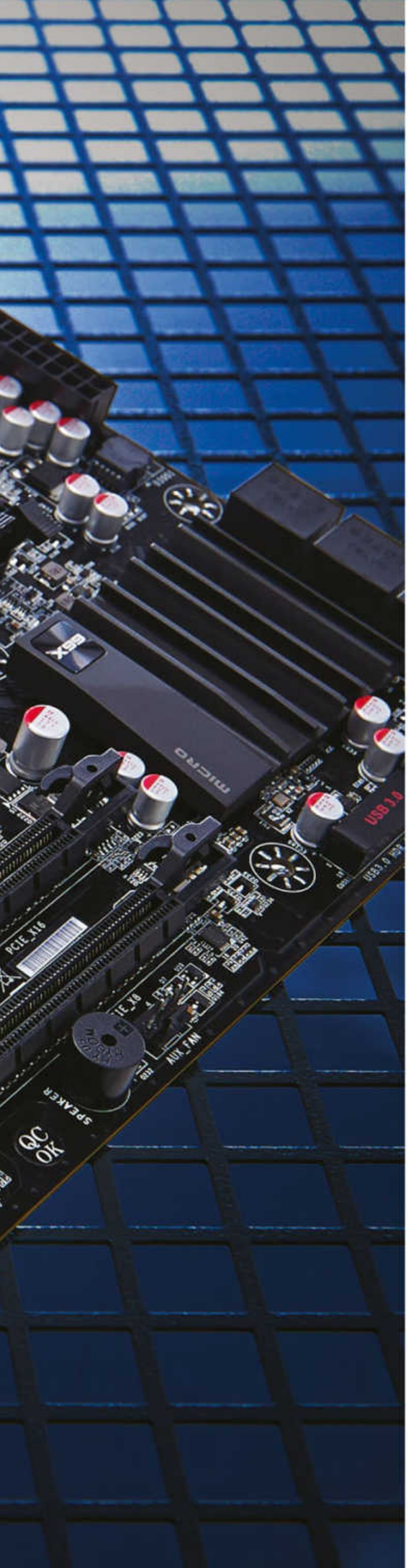
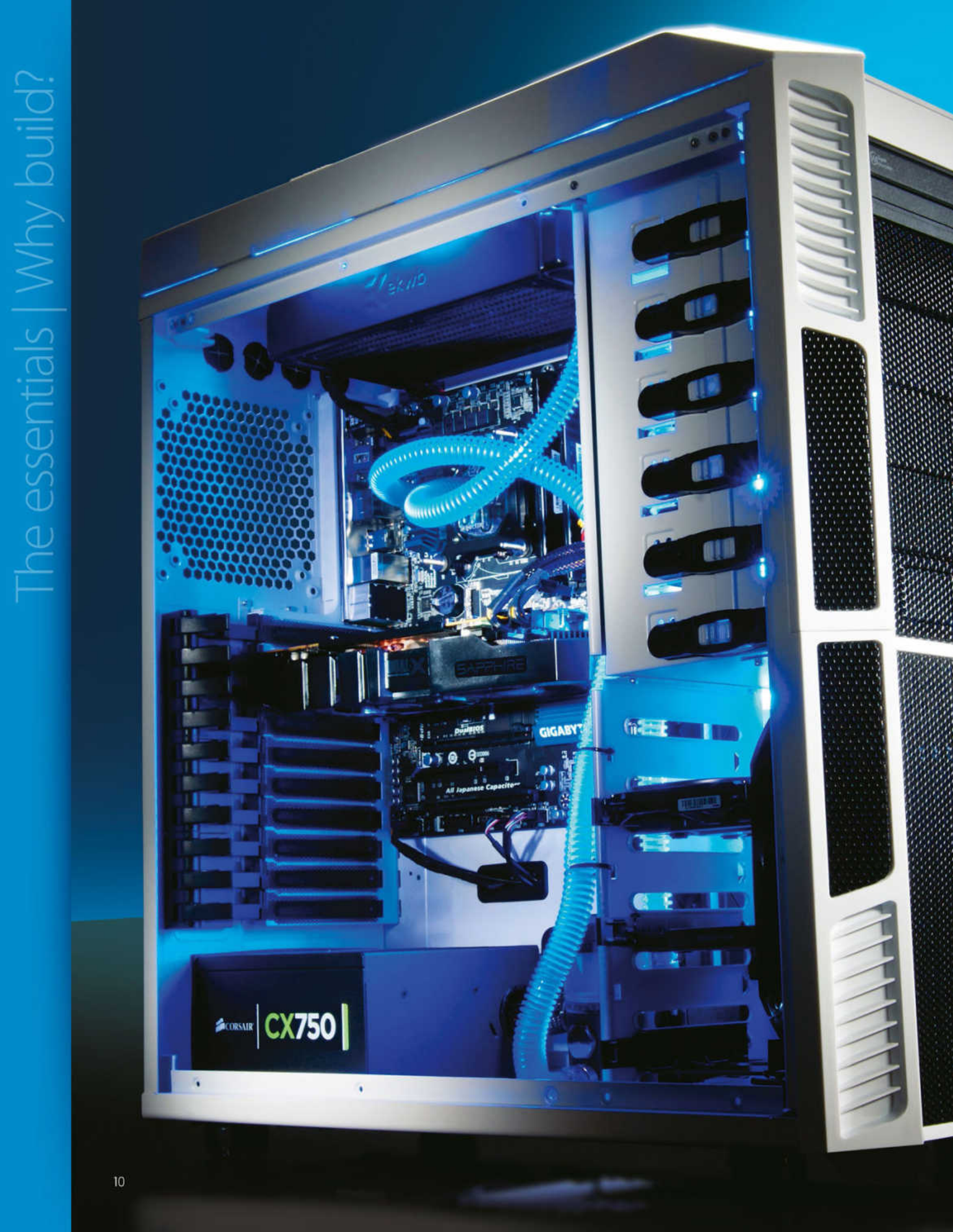


THE ULTIMATE
PC Building HANDBOOK

THE ESSENTIALS

YOUR PC BUILDING JOURNEY STARTS HERE


CORSAIR
CX750
GIGABYTE
All Japanese Capacitor

WHY BUILD YOUR OWN PC?

BUILDING YOUR OWN PC IS ONE OF THE BEST HOME-BREW TASKS YOU'LL EVER UNDERTAKE. YOU PROBABLY ALREADY HAVE YOUR REASONS – BUT IF YOU'RE UNSURE, LET US SELL IT TO YOU!

Over the last few decades the mass market has made us a little bit lazy. Prior to just buying whatever we needed, we would build it – a world of engineers, builders and grafters forging things with our bare hands. But nowadays, you know there's someone sat somewhere in a factory on the other side of the world, churning out everything you could ever want, so you don't have to.

But doing it yourself has become more and more popular in recent years, and plenty of people are having a good at doing it themselves, whether it's assembling a bicycle from scratch, turning a tree into a dining room table, and even – the reason why we're here – building a PC.

Making your own PC consists of buying the parts you need and putting it all together, which isn't as tricky as it sounds. It isn't always cheaper to do it this way (though, it can be), but the art of building your own is the path to pride and accomplishment.

> "IF YOU NEED A PC FOR POWER, A HOME-BUILT DESKTOP PC IS PERFECT"

Handily, it also emboldens us to fix our creations if they ever go wrong, because we understand the whys and wherefores. So, by putting together a computer yourself, you may be able to save a potentially expensive bill down the road.

Building your own PC also gives you a much greater set of options to play with, allowing you to get exactly the kind of PC you want, in exactly the specification you desire. For example, you could use the world smallest PC case, but stuff the biggest, most powerful graphics card inside, just because you can. Perhaps you shouldn't, but you could. Even the most influential computer manufacturers don't offer that depth of customization.

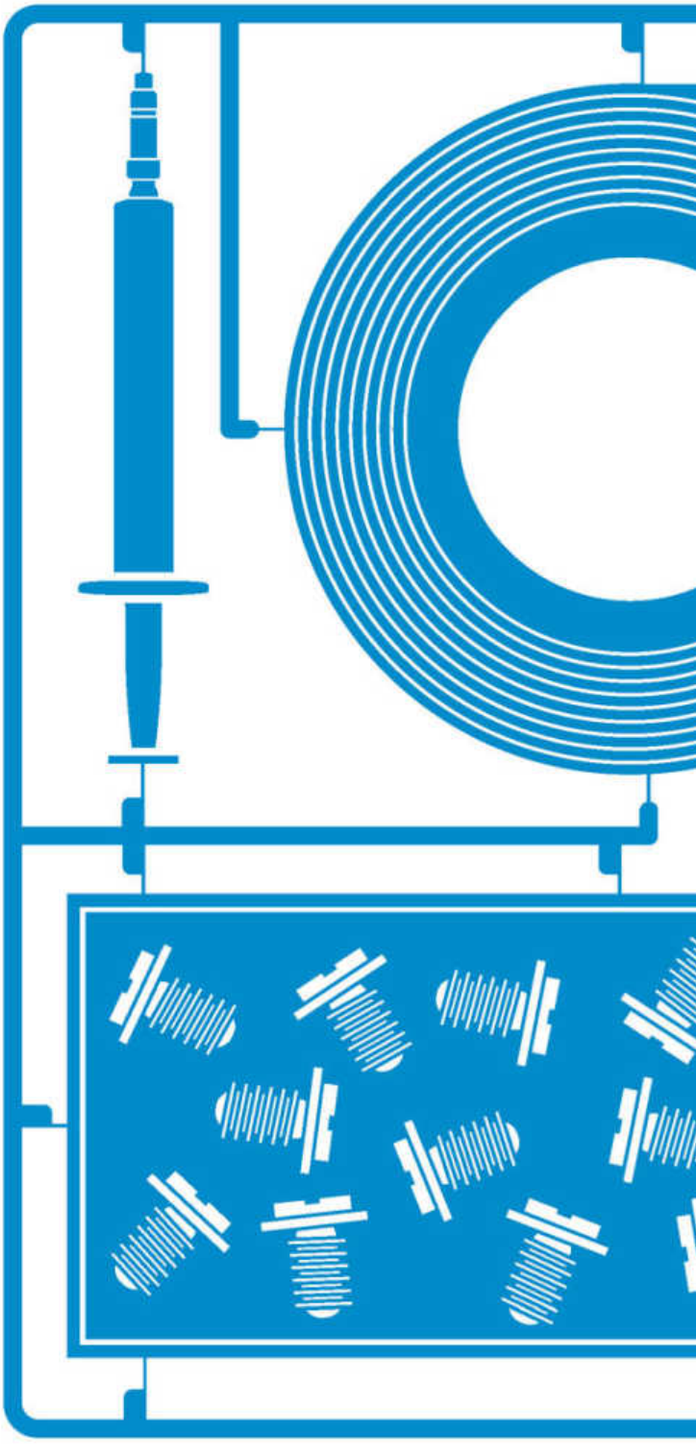
Choosing your own parts also allows you to choose the best, most reliable parts you can afford, so – unlike a shop-built PC, you don't have to worry that certain components – such as the memory or power supply - aren't up to scratch.

Building your own PC isn't necessarily something you would do if all you want is a machine to surf the web with, or you're after a laptop or tablet. But if you need a PC for power-sucking tasks, and want some serious screen real estate – whether it's for design or just playing games – a home-built desktop PC is perfect. Because let's face it – nothing really beats a keyboard and mouse.

THE ESSENTIAL PC BUILDER'S TOOLKIT

GET THE RIGHT TOOLS BEFORE YOU START BUILDING

If you're not sure what you need to start your PC build, we've covered off all the essentials you'll ever need, so now all you need is the parts and you can start putting it all together.



✓ Magnet-on-a-stick

If you've ever worked on a car engine before, you'll know that dropping a screw into the engine and not hearing it fall on the floor is every person's worst nightmare. It's not quite as serious if you do the same thing whilst building a PC, admittedly, but having a magnetic stick ready to retrieve any screws that have lodged down the side of a motherboard, or fallen inside the bottom of a chassis, could save you a whole load of time, as it will save you having to dissemble things to gain access. Obviously, if you already own a magnetic screwdriver, then this might be overkill, but a magnetic stick could help you to reach into places that a magnetic screwdriver might not be able to.

✓ Screwdriver

A bit of a no-brainer this really – if you're planning to build a PC, a screwdriver is really the minimum you're going to need to get you through. There are a lot of screws holding a PC together, so make sure you get a screwdriver with a Philips head – that's the bare minimum you'll need. Ideally, we'd recommend getting one that's got different types and sizes of screw heads, and get one with an extendable collar, as it'll make it much easier to access those screws that are hidden deep within your PC case. If you can, find a screwdriver with a magnetic bit inside, as it'll make retrieving any screws that fall into the case a lot easier.

✓ Torch

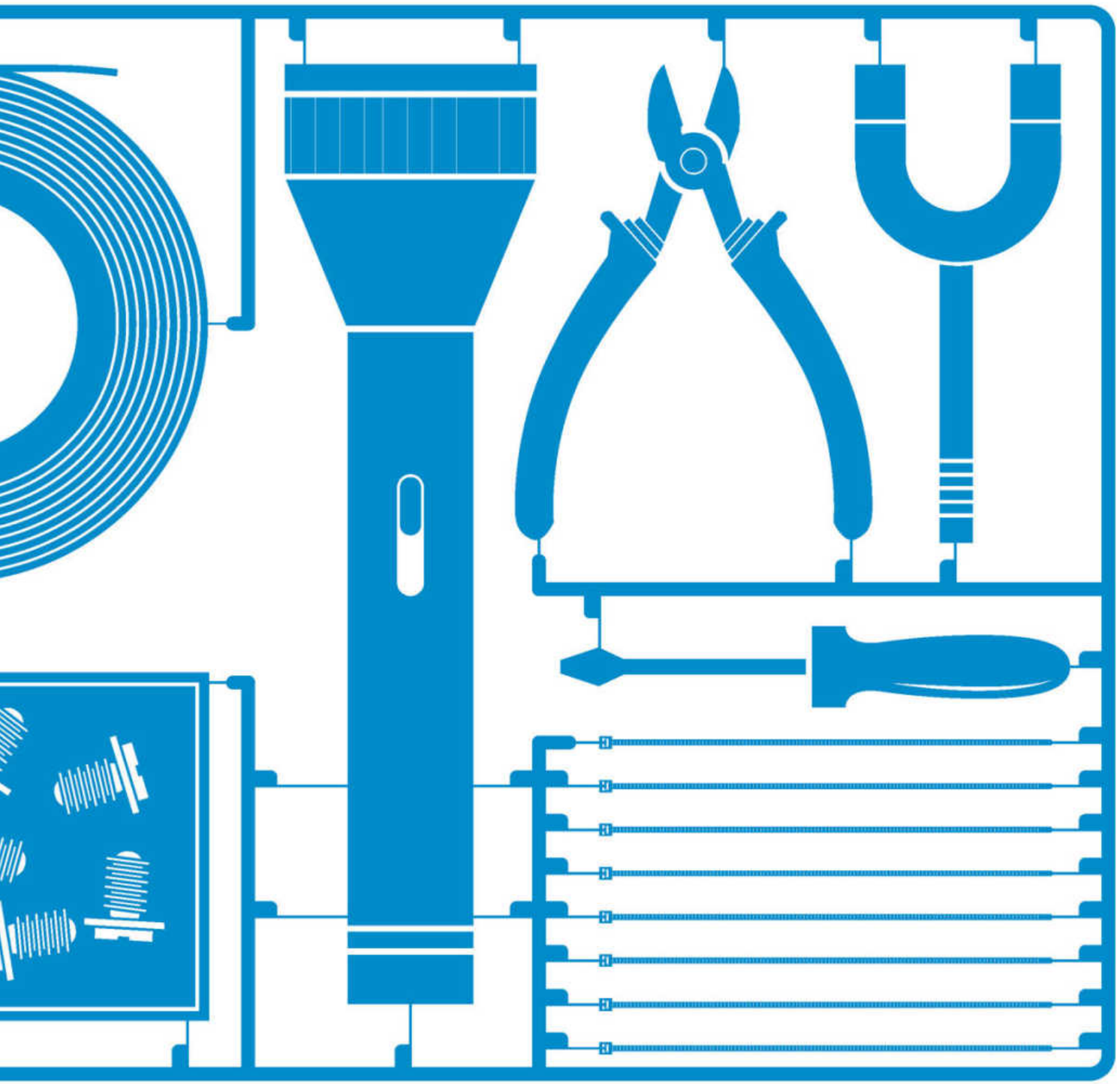
No matter how bright the room in which you're working on your PC is, the inside of PC cases can be dark places – especially the bigger ones that have lots of different compartments for each component. So, a torch is a wondrous thing to have, as it allows you to see exactly what you're doing during your build. It also allows you to find small items that have gone awry, like little screws. Ideally, instead of getting yourself the biggest, brightest thing you can find, which you'll struggle to hold, opt for a head torch, such as the kind you can get from outdoor shops. The advantage of these is that not only will your hands be free to work on your PC, you'll be able to shine a light exactly where you're looking at.

✓ Zip ties

No self-respecting DIY'er has a toolkit without a set of zip ties – they really are a must-own item. Zip ties – or cable ties, as they're known - can fix a multitude of sins, allow you to fix things in place as you work, and in the case of PC building, it enables you to tidy up the interior of your chassis. By cable tying various cables together, you can keep them organized and away from the rest of the interior components, avoiding potential damage and keeping the airflow in your case to a maximum. It also just keeps things looking really neat – great for those with a penchant for OCD – and makes it easy to work on your PC in future.

✓ Wire cutters

If you're going the whole hog of cable tying your wires in place inside your PC case, you might want to go that extra mile and make sure you remove any excess bits of cable, for maximum neatness. A pair of cable cutters ensure you can snip those remaining end bits of plastic once your wires are set in exactly the place you want them. They're also ideal if you want to remove unused connectors from your components, such as an additional power connector for a fan that isn't actually attached to your motherboard and isn't being used.

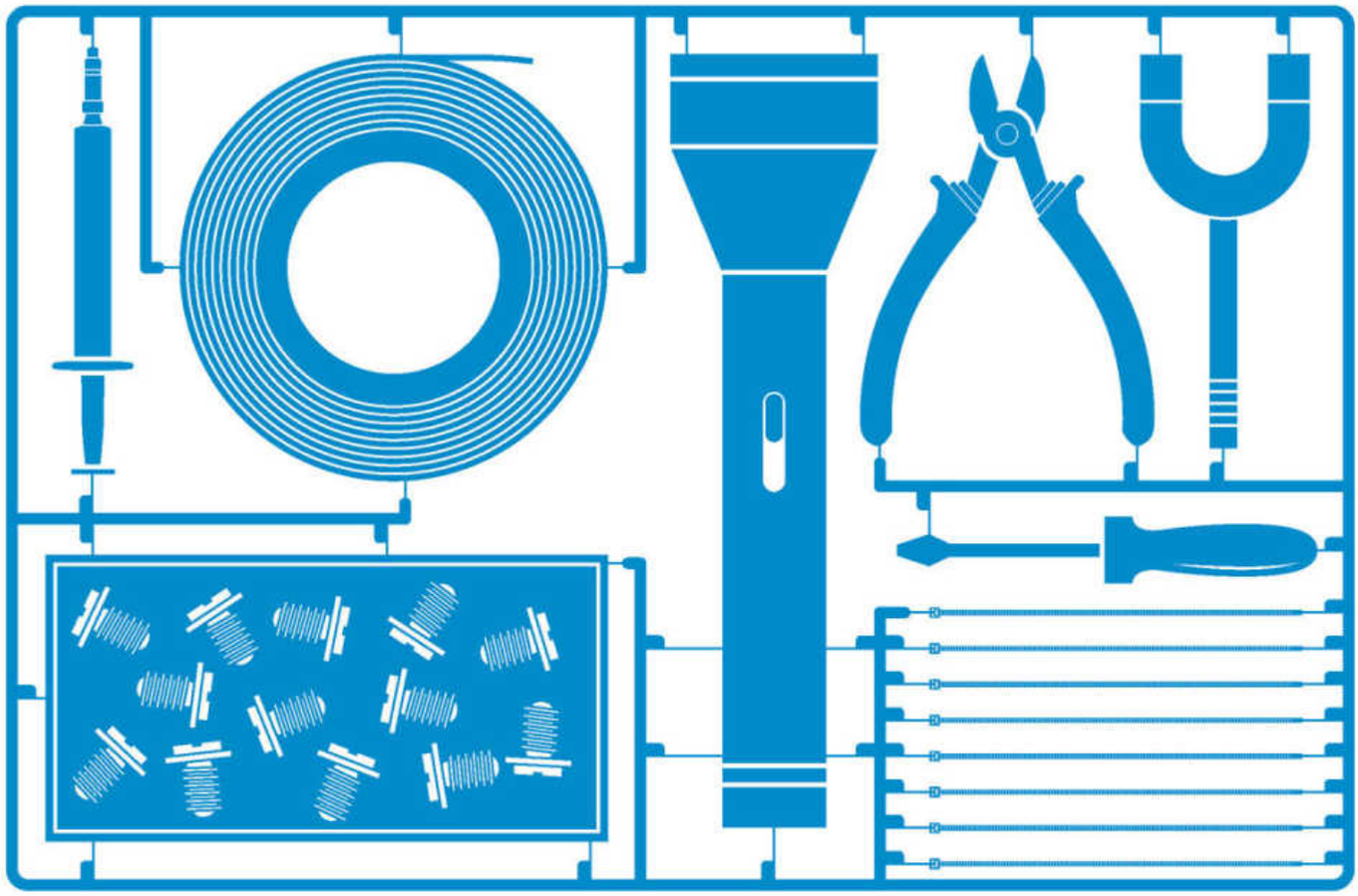


Screw fix

With the multitude of screws that you'll be using to build your PC, a system that allows you to keep track of them all is essential. For starters, you should get a tray tidy to store all your screws in, with separate compartments for keeping different types of screw properly organized. A toolbox may already come with a tray tidy, so if that's the case – make sure you use it.

Another essential screw organizing tool is a magnetic tray. Keep this close to hand and you can simply store any screws you're currently using in this tray. Its powerful magnetism will keep screws from dropping out and falling down a hole in the floorboard. Having said this, it's always worth keeping a selection of spare screws in different sizes, in case you do happen to lose one, or three.

"IT'S ALWAYS WORTH KEEPING A SELECTION OF SPARE SCREWS IN DIFFERENT SIZES"



Thermal compound

It's important to keep your components cool – the cooler they are, the better they will perform, the more reliable they'll be and the longer they will last. One of the most crucial components in your PC build is the processor, which produces a lot of heat and just so happens to be one of the most expensive parts. You don't want this to fail, so when you're coming to seating the heat sink onto the processor, you should always apply fresh thermal paste. Even when you remove the heatsink at any point, get rid of the old stuff and apply the paste new. Good paste ensures that all the bad heat is transferred away from the processor and into the heat sink, which can then be pushed away and out of the case.

Electrical tape

This is as about as basic as it gets in your PC building tool kit, even more so than cable ties, but electrical tape also happens to be of equal usefulness. If you don't like the thought of using cable ties, you can use tape to keep your computer cables under control, though electrical tape can also be used to compliment your use of cable ties. If you've tied some cables, but can't actually get them positioned just how you like, you can then tape those cables to the inside of the case to move them into a specific place and keep them out of the way.

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SET UP YOUR WORKSPACE

LEARN THE TRICKS THAT WILL HELP YOU TO BUILD A PC QUICKER, SAFER AND SMARTER

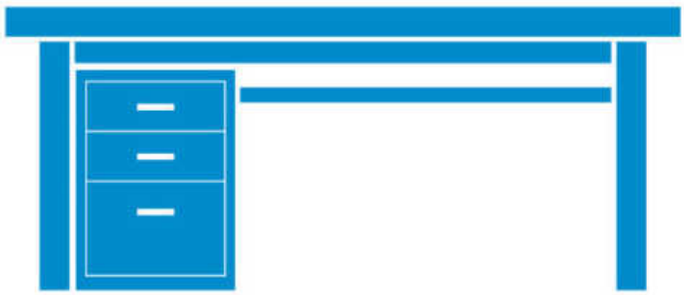
If you're planning to get serious about building up your PC – whether it's because you just want to do the best job you can, or because you're planning on doing it regularly – it pays to prepare a great workspace, allowing you to work more comfortably and with all the right tools to do the job properly.

✓ Find some space

Though the nearest floor might seem like an ideal place to begin assembling a PC, think about the consequences of what you're doing. A floor is very low down, so if you're working on a PC for some time it could give you terrible backache, so choose a surface that will allow you to work comfortably while you're standing. Secondly, if you're working near a floor with lots of gaps in floorboards, or near heavy pieces of furniture, you may drop something and never see it again. So, choose an area of your house (or shed/garage) that gives you a lot of space to work in comfortably, as you'll no doubt want extra room as you go along.

✓ Protect against nasties

If you're serious about building PCs and want them to last as long as possible, it's vital that you keep your machines properly protected against electrical issues, both when you're building them and using them later on. A surge protector with a high joule rating will keep your kit safe from high energy spikes, while a Uninterrupted Power Supply will keep your PC safe from brownouts, or other low energy surges. The other benefit to using a surge protector is that you get access to additional sockets which you'll need when either using a PC or building one up, as you'll need to test various parts as you go. Most of the modern surge protectors also have cleverly arrange sockets, allowing you to plug in all types of plug, without having to sacrifice one to an awkward plug.



✓ Employ a cleaning kit

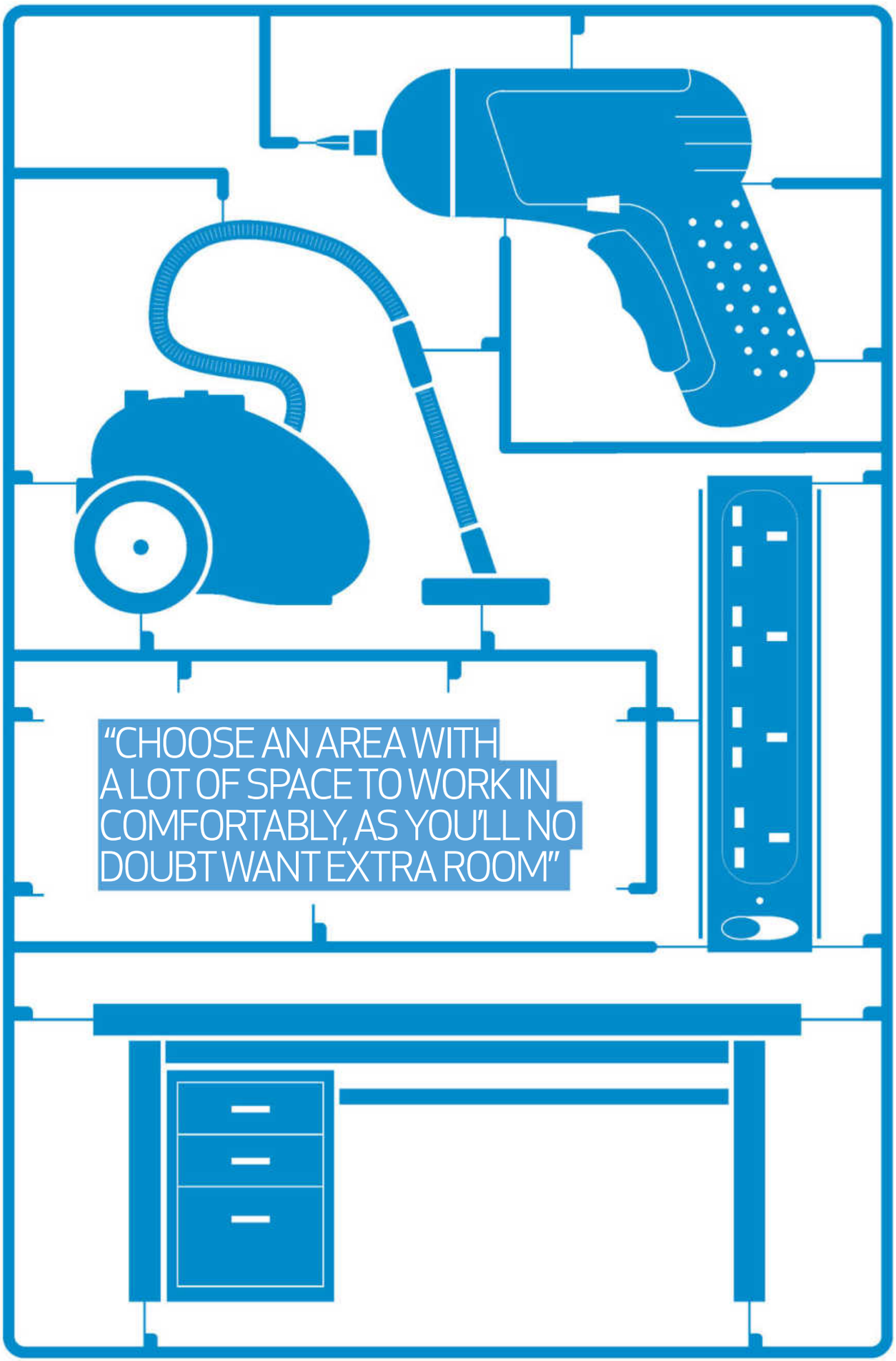
Every pro-style PC builder should have a cleaning kit within arm's reach. Before you begin assembling a PC, you should make sure all the parts are clean and free of dust, and you'll also need to regularly do this afterwards to keep your machines properly maintained, otherwise they can become slow, unreliable and really noisy, as the fans become clogged with dust. To perform a thorough clean up, either pre or post build, you'll need a can of compressed air for blowing out the majority of dust, and a vacuum cleaner to pick up everything as it comes out. Don't be tempted to vacuum the components inside the case, though you can happily vacuum on the outside of the case, near vents, to get rid of any remaining dust. Use a cotton swab to get rid of any persistent bits that remain in-between components.

✓ Prep your working area

Once you've selected an area that you want to work in, now you can select the workspace that will house your PC building projects. Rather than using your kitchen floor or dining table, get a table specifically for the job, and ideally one that you can fold away later when you're not using it. Make sure the surface top is smooth enough not to scratch anything you're working with, but you also want it to be grippy enough so that things don't slide off. A rubber sheet that you can lay on the entirety of the table surface would tick both boxes, and also helps to deal with static, which will prevent any accidental discharges from damaging components as you work.

✓ Get more power

A regular screwdriver is fine if you're just building the occasional PC, but if you're planning on doing it regularly you need something that will take the hard work out of it. A power screwdriver is an essential tool that will allow you to quickly and effortlessly attach screws – and equally of importance – undo them, if you ever need to swap parts around or perform general maintenance. Due to the tight confines of a PC case, it's worth looking for a power screwdriver that has an adjustable handle as it'll allow you to adjust the angle you're working at. Be careful, though - before you start using your power screwdriver, make sure that you've done the crucial job of engaging the threads, as you risk cross threading and ruining the thread and/or screw.

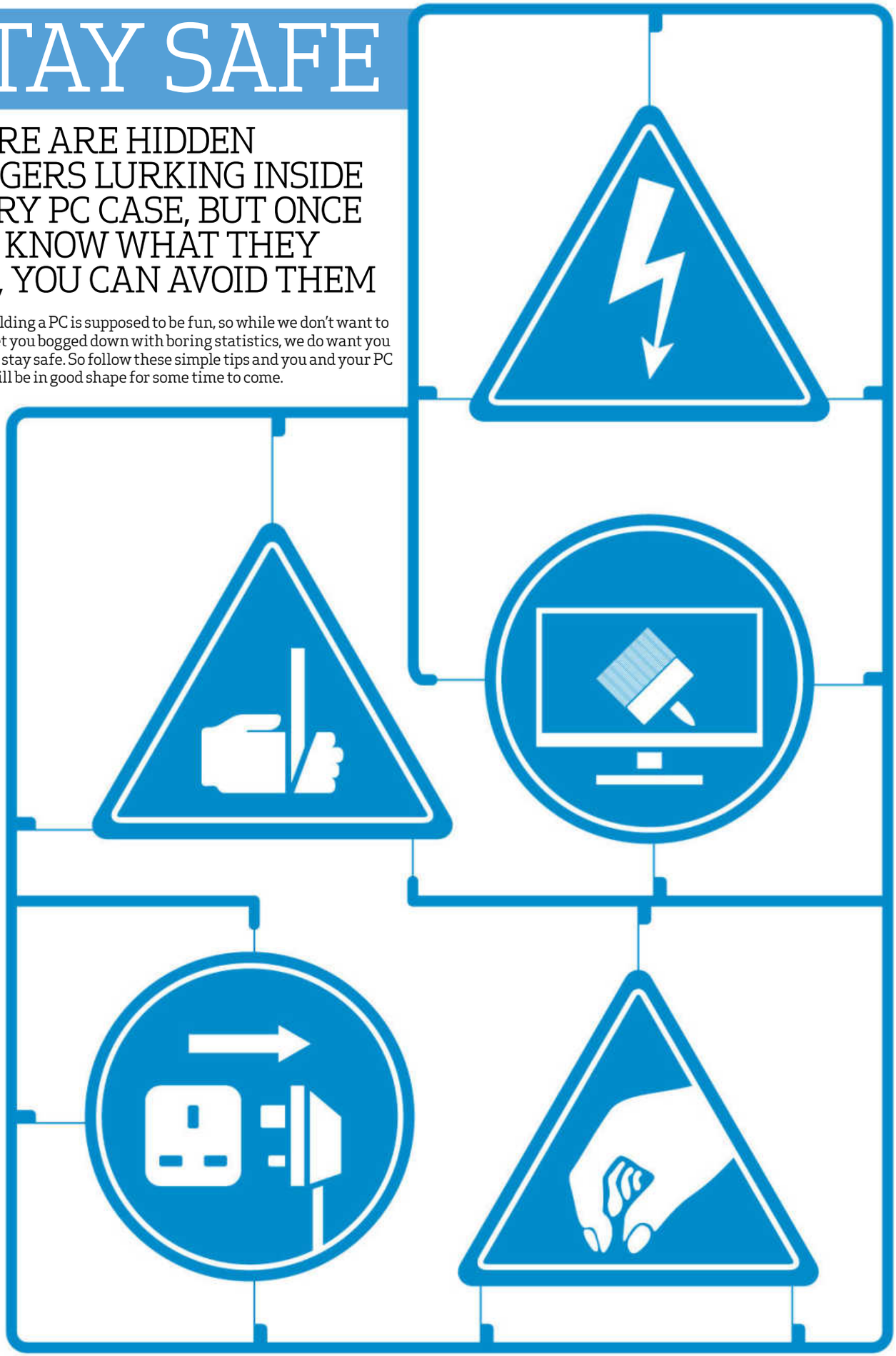


"CHOOSE AN AREA WITH A LOT OF SPACE TO WORK IN COMFORTABLY, AS YOU'LL NO DOUBT WANT EXTRA ROOM"

STAY SAFE

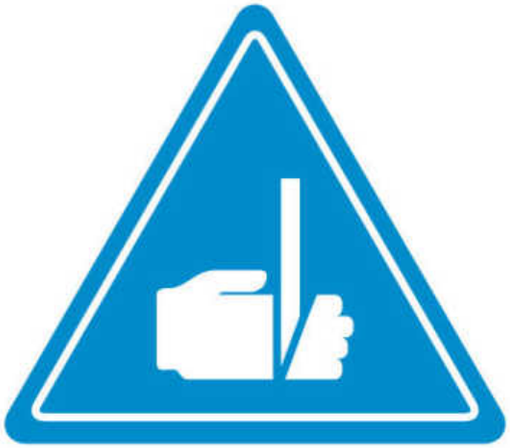
THERE ARE HIDDEN DANGERS LURKING INSIDE EVERY PC CASE, BUT ONCE YOU KNOW WHAT THEY ARE, YOU CAN AVOID THEM

Building a PC is supposed to be fun, so while we don't want to get you bogged down with boring statistics, we do want you to stay safe. So follow these simple tips and you and your PC will be in good shape for some time to come.

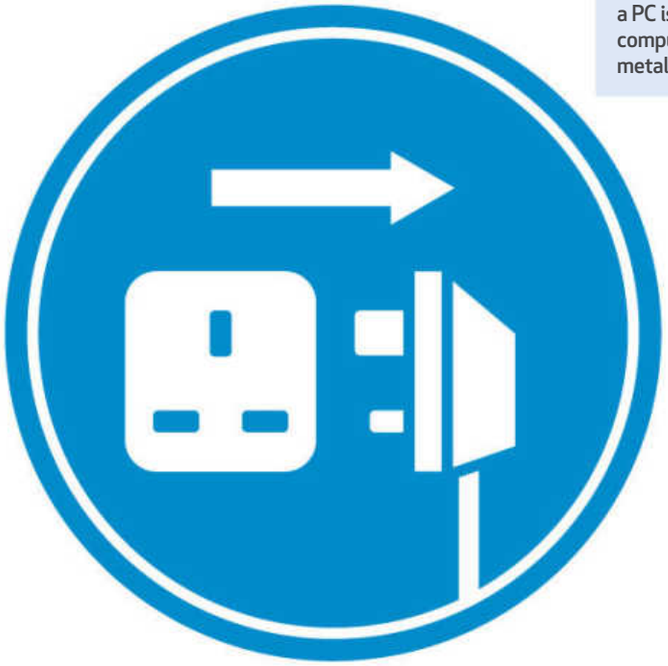


Prevent static charge

PC components are especially sensitive to static charge, and it can really do some damage if an excessive amount builds up – even fry your components, if worst comes to worse. So how do you prevent this from happening? Easy – you just need to prevent yourself from creating static charge in the first place. The first step is to prepare your workspace for PC building, which you can do by getting an anti-static mat to put your PC and its components on as you're working. Secondly, get an anti-static wrist band so that any static you build up won't be transmitted on the things you're working on. Finally, keep your PC plugged into a power outlet, but keep the power supply switched off.



"DON'T PANIC, BUT TAKE CARE WHILST WORKING WITH THINGS THAT CAN HARM"



Watch out for sharp edges

Building a PC might seem like a relatively safe pastime – and it is, so don't start to panic – but you do still need to take care whilst working with things that can harm, in the same way that any DIY activity potentially can. The main concern when working on a PC is the case. Practically all computer cases are built out of metal, and most, if not all, have really sharp edges that you need to watch out. The biggest offenders tend to be around the inside, generally anywhere there is a cut out, but the worst is the metal plate that you affix to the back of the case to shroud the ports – this bit is seriously sharp. Keep some plasters close by, just in case, but always work with caution.

Handle parts carefully

Computers may look like they're built like brick walls, and while the cases generally are, the bits inside aren't quite as hardy. Components are quite fragile, so it's worth handling them with extra care. You don't want to fit a new graphics card to the motherboard and accidentally snap something that might render it useless. Be especially careful with small pin connections that can get bent or completely broken easily when you're attaching plugs, so just use firm but not excessive force. When it comes to handling components, always hold them from the edges which not only prevents you from damaging things, it also means that any potential charge built up in your hands won't attack the main electrical gubbins – you could fry bits as easily as they could you.

Disconnect power

The last thing you need when you're happily working away at putting together your PC, is to suddenly find that you're getting a rather hefty electric shock and the next thing you know you're at A&E. To prevent big surprises like this, always remember to keep the power disconnected when doing any kind of work on the inside. You don't have to pull the plug from the wall, just remember to flick the switch to off on the back of the PSU, where the wire from the plug connects to. Do this each time before you open up the case, even if you're simply planning to peer inside, as it can be easy to forget.

Take care of your pc

Unless you're planning to put some serious elbow grease in, cleaning your PC is a relatively simple task that shouldn't involve any self-harm, but as was mentioned previously, be wary of sharp edges. Though quite safe, it's possible to damage your machine if you use an improper cleaning regime. It sounds obvious, but don't be tempted to apply water or cleaning solutions anywhere near the inside, though careful use on the outside would be fine, and don't use cleaning cloths to remove dust. It's all about being as gentle as possible. First of all, switch the PSU off, and then carefully blow out dust using compressed air – making sure it actually leaves the case, rather than coating everything else – and that should keep your PC running nicely.


AOC

THE ULTIMATE
PC Building HANDBOOK

CORE GEAR

GET THIS KIT RIGHT AND THE REST WILL FOLLOW


RADEON
RADEON

CHOOSE YOUR PC'S PERFECT COMPONENTS

YOU GET BACK WHAT YOU PUT IN. DISCOVER HOW TO CHOOSE THE RIGHT PARTS FOR YOUR PERFECT BUILD AS WE CONSTRUCT A QUALITY £700 PC

Design improvements mean that it's never been easier to build your own PC – but it's still difficult to pick the right components for a brand new build. Choosing the wrong parts comes with a host of potential pitfalls.

Some aren't serious, but others could be terminal. Plugging an SSD into the wrong SATA port only limits speeds, but your PC won't even boot if the processor and motherboard aren't compatible. Picking a motherboard without certain chipsets or slots makes it tricky to fit future components – and choosing a power supply without much grunt will make a graphics upgrade difficult.

This guide makes it easier to pick the correct components for any kind of PC – from bargain-basement machines to full-throttle gaming systems. Every major component is covered, and we've examined the relationships between these parts to ensure you'll pick components that work well together.

We've taken our own advice and designed a £699 PC – the sweet spot that enables high-end computing and top-tier gaming without breaking the bank.

The little details

Pay attention to the fine print as well as the big picture when building a PC, and you'll be much happier.

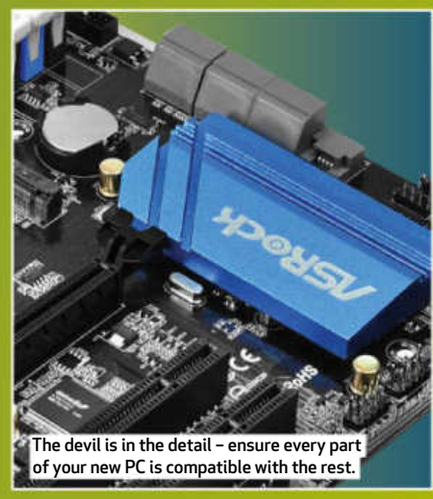
Some motherboards are littered with smaller features worth consideration. Check the heatsinks that surround the processor, for instance – they could make it difficult to install larger heatsinks. The same goes for the memory sockets, which can cause cooler conflicts if they're too close to the processor.

If you're keen on tweaking, check the rest of the motherboard. Higher-end boards have on-board buttons, voltage monitoring points, dual-UEFI software modes and more options that are handy for enthusiasts.

Before buying a case, check what fans are included – most include one or two. If you're building a more powerful machine, consider investing in more cooling; most cases support two or three 120mm fans at the front, two or more in the roof, and even fans in the base.

A host of other steps can be taken to ensure the build goes smoothly. Don't forget to install the small golden risers before screwing in the motherboard, and don't forget to plug in the connectors at the bottom of the motherboard, too – these wire up the power and reset buttons at the front of your case.

There are plenty of common pitfalls when it comes to choosing components that work well together – and then putting them together when they've all arrived. Follow these tips to avoid common mistakes, and you're less likely to go wrong.



The devil is in the detail – ensure every part of your new PC is compatible with the rest.

CPU AND GPU

The processor and graphics card are two of the most important components inside a PC; none go as far when it comes to determining how a system will handle intensive software, multi-tasking and top-tier games.

They're closely linked. If you've got a fantastic processor but a poor graphics card, demanding tasks will be held up as the GPU struggles to handle its load. The same is true at the other end of the scale – a great GPU can be hamstrung by a weak processor.

Several factors need to be considered when choosing processors. The clock speed should be your first port of call – the higher that figure, the faster the chip. It's less of an issue these days, because most processors have ample pace – as long as you've got more than 3GHz, you should be OK.

Most processors use temporary overclocking to generate more speed. This is called boosting, but it won't make a huge difference – you'll only get a few hundred extra megahertz, and not necessarily across every core.

Also consider cores. Low-end chips typically come with at least two, which is enough for lighter computing, but anything more intensive – including high-end gaming – requires four. It's even better if the chip has Hyper-Threading, which means each core addresses two concurrent tasks. AMD processors function similarly – like Intel, its quad-core parts handle eight application threads.

Want to overclock? Then choose your CPU wisely.

It's easy to spot which chips are ripe for overclocking; Intel parts with unlocked multipliers have the 'K' suffix, and overclockable AMD hardware is labelled as 'Black Edition'. AMD and Intel both sell quad-core processors with multi-threaded operations, high clock speeds and boosting. Your choice determines your motherboard – and, therefore, a host of other features.

Just as much goes into picking a graphics card. A good GPU needs a potent combination of stream processors, clock speed and fast memory. The stream processor functions similarly to processor cores, but the different demands of graphical workloads mean that you'll find hundreds inside low-end GPU cores, and thousands inside high-end cards. They're clocked at certain speeds, and the higher both these figures are the better.

These days, you'll want at least 3GB of GDDR5 for serious gaming, and the faster the better. High-end cards have more, and soon you'll want 8GB. That's because the Xbox One and PS4 have 8GB of RAM, and many games are now developed for consoles and ported to PCs – so memory parity is important.

Graphics card choices don't stop at the PCB. Consider the size of the card, because some won't fit inside smaller cases. Also check that the heatsink won't block other motherboard slots, and ensure that the power supply has the correct

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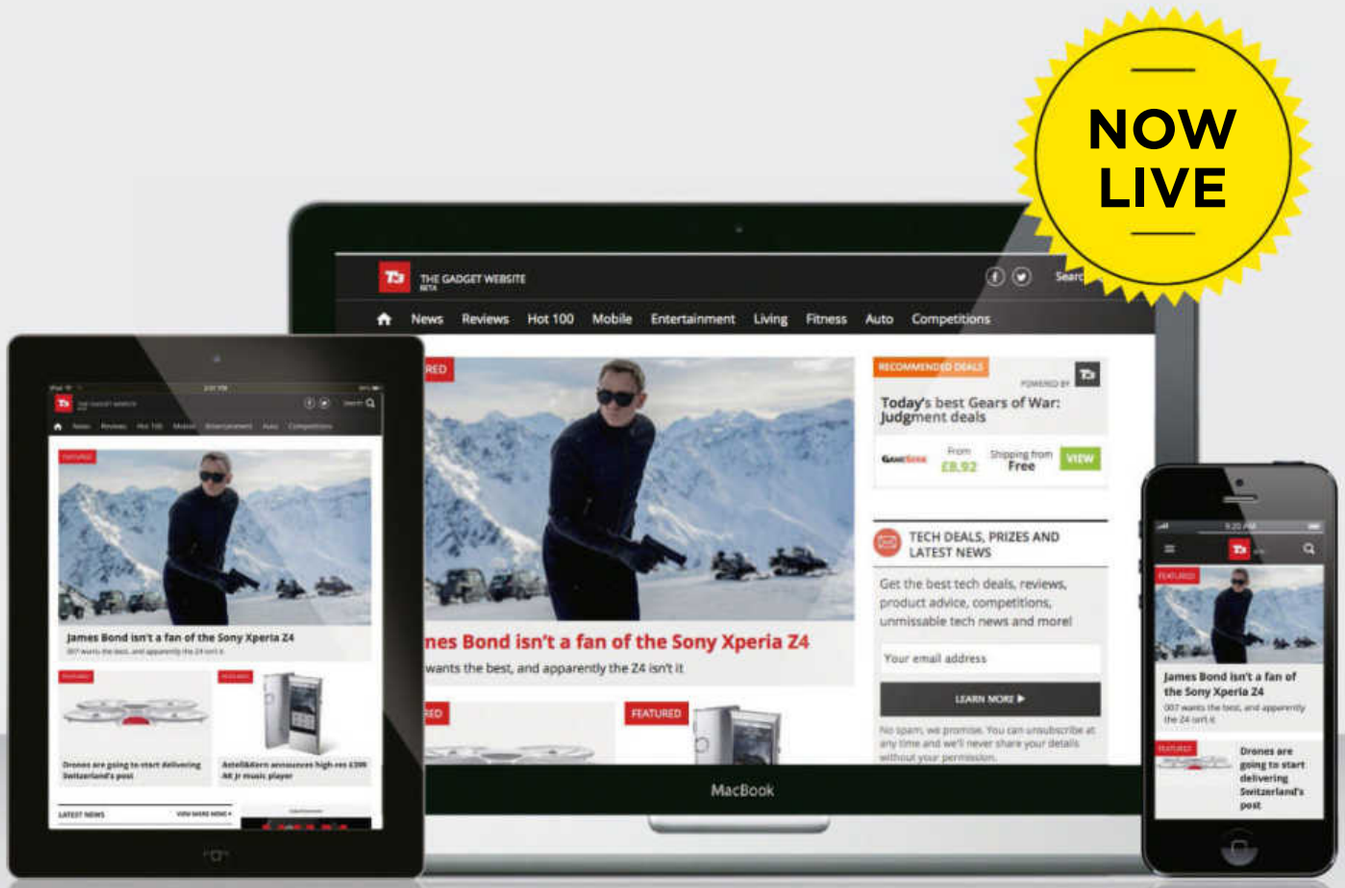

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As you'd expect, the better the GPU, the more you'll pay.

connectors – some high-end cards required two eight-pin plugs.

If you're buying a low-end processor, don't indulge in one of the market's most expensive graphics cards – you won't see the full potential of a £500 card if it's underpinned by an Intel Pentium or Core i3 part. That bottlenecking is less of an issue if you're building at the mid-range or beyond – processors and graphics cards have enough grunt to get the job done.

It's part of the reason why we've chosen Intel's Core i5-4670K for our build. It ticks every box: four 3.4GHz Hyper-Threaded cores provide excellent power, two cores can use Turbo Boost to hit 3.8GHz, and there's plenty of cache. Its £160 price is high, but it's worth it – this is a crucial component.

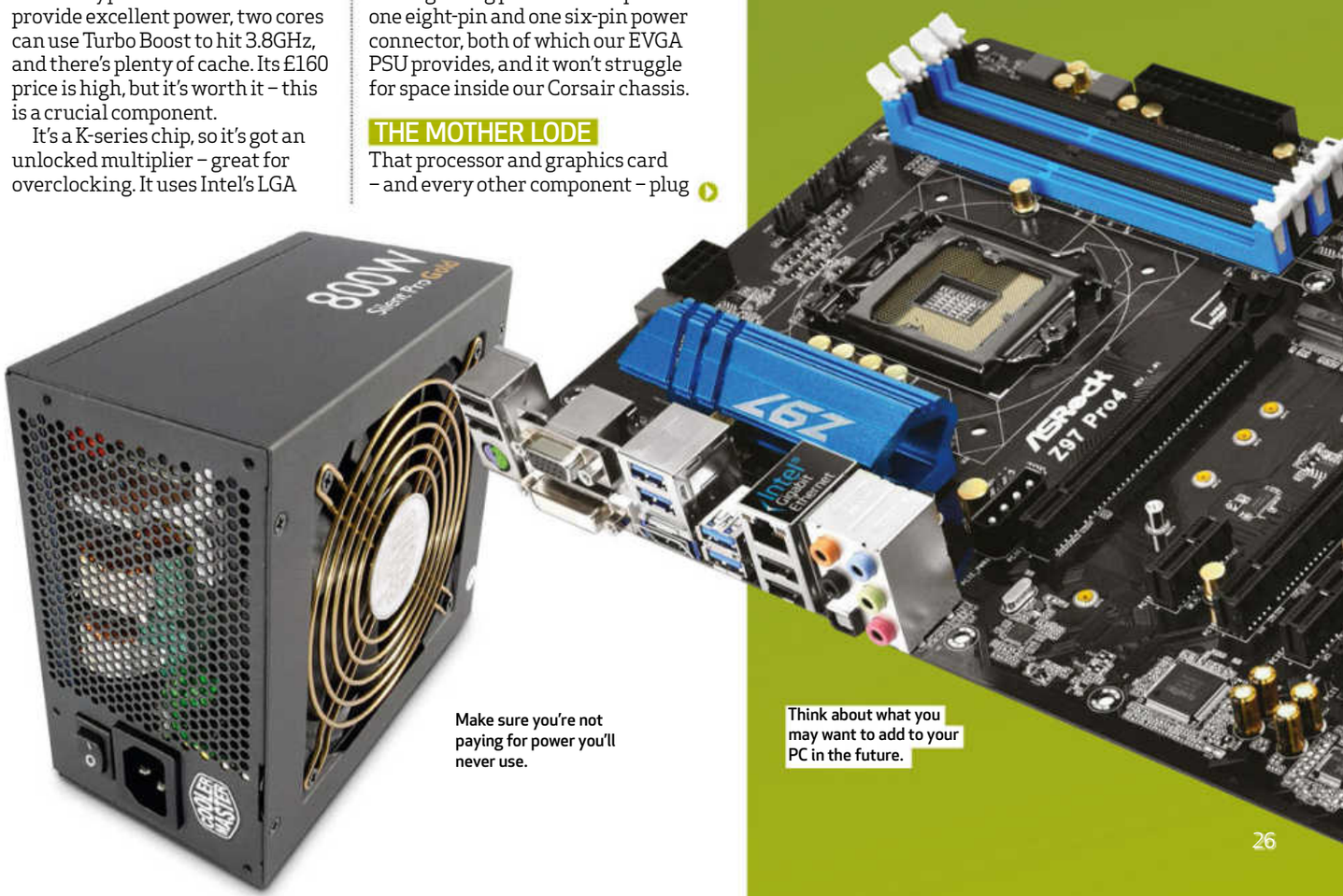
It's a K-series chip, so it's got an unlocked multiplier – great for overclocking. It uses Intel's LGA 1150 processor socket, which means it's compatible with many motherboards. It trades blows with AMD's FX-9370, which costs the same, but Intel wins in several performance categories and has better power consumption.

We're switching to AMD for our graphics. The Radeon R9 280X has dipped below £200 – our card of choice, an XFX model, costs £189 – and it beats Nvidia's pricier GeForce GTX 770 in several benchmarks. There's even enough power to play many games across three screens.

We've not just chosen this card for its gaming prowess. It requires one eight-pin and one six-pin power connector, both of which our EVGA PSU provides, and it won't struggle for space inside our Corsair chassis.

THE MOTHER LODE

That processor and graphics card – and every other component – plug



Make sure you're not paying for power you'll never use.

Think about what you may want to add to your PC in the future.

Room to grow

Our rig has been designed to work well now while also offering plenty of room for future upgrades. It's always worth keeping an eye on the future when putting together a new system, because it's usually cheaper and easier to give an existing machine a boost than to buy a new rig.

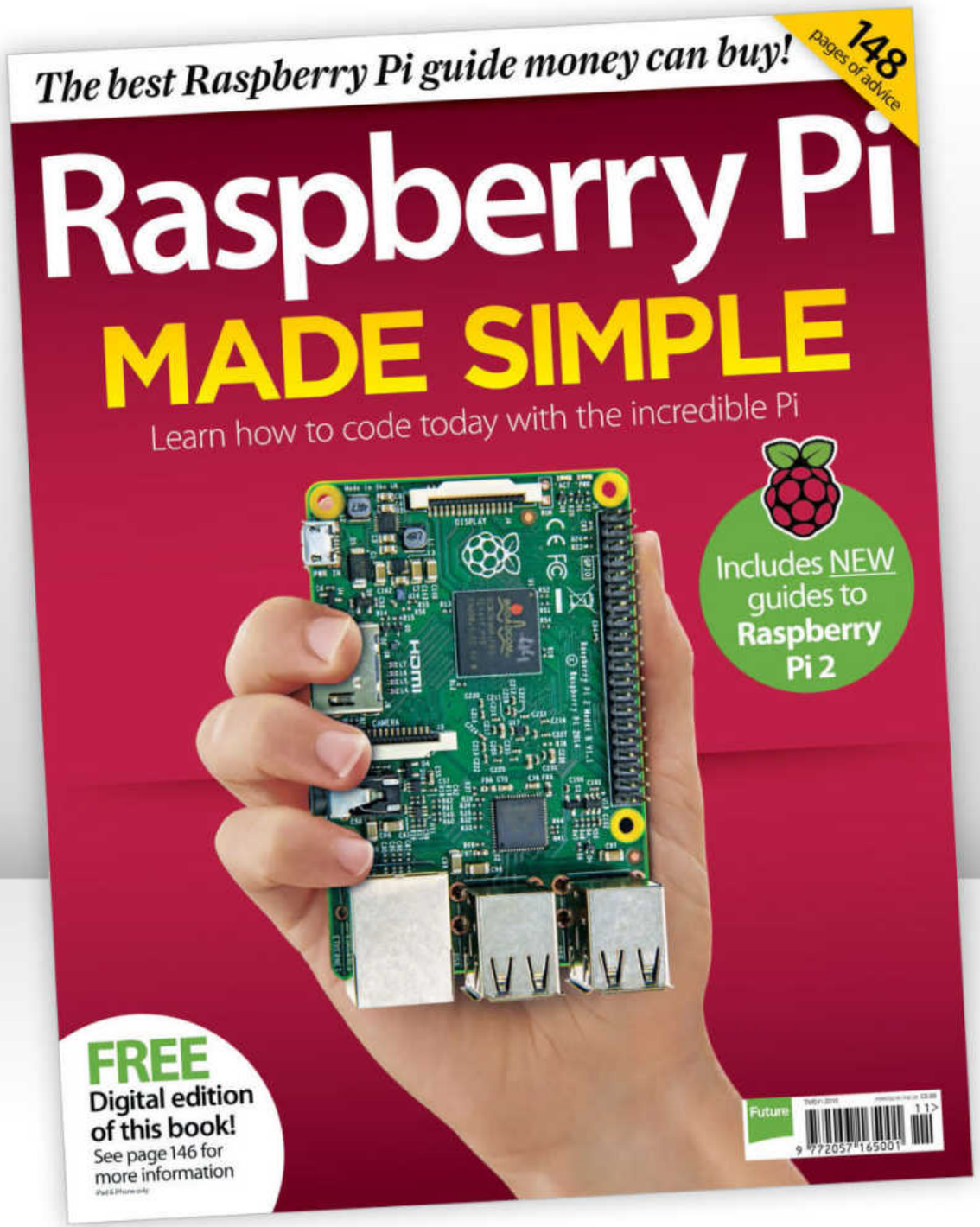
The motherboard is key to upgrading. If you've picked a board with a second PCI-Express x16 slot – and it runs at 8x speed, at least – then you've got enough bandwidth to fit a second graphics card, which can theoretically double gaming performance.

Our MSI board has an LGA 1150 processor socket, which means that the Core i5 processor can be swapped easily for a faster chip. The same is true if you're building on the AMD side of the fence – the AM3+ socket used for FX processors will continue to be used for the foreseeable future.

Our board also has an M.2 connector. It's a bit more obscure, but it's worth having one of these, because it's likely to be the next big format used for SSD storage. The switch will begin to happen soon, too, because top-end SSDs are now saturating the bandwidth offered by their SATA 6Gbps connectors.

Other areas are worth consideration for future upgrades. Extra 2.5-inch and 3.5-inch bays can be used for more storage; spare memory sockets can be used to add a second pair of dual-channel memory sticks; and PCI-Express x1 and PCI slots can both be used for other expansion cards – Wi-Fi and sound cards are both popular additions to PCs.

CODING, PROJECTS AND LINUX SKILLS



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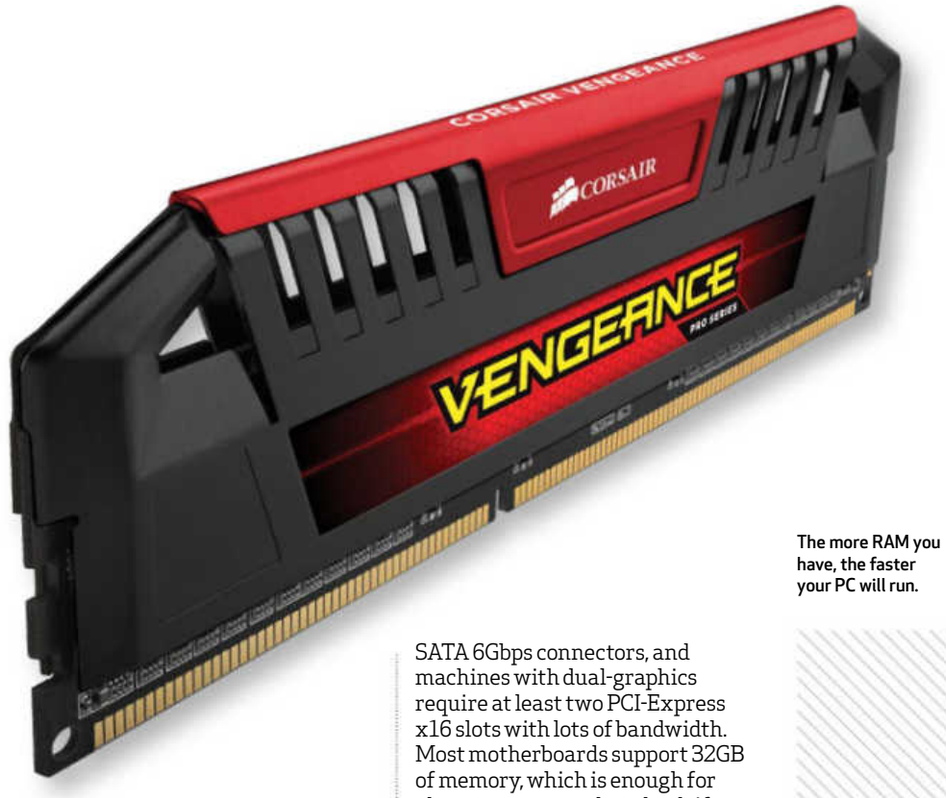


The more RAM you have, the faster your PC will run.

into the motherboard. It's the one bit of kit that links every part, so it's one of the most important things to get right.

Motherboards are available in several different form factors. These classifications govern the size of the board, and help determine its features. The largest use the ATX form factor, and below that there's Micro-ATX. Beyond that you'll find Mini-ITX, but that's not worth considering unless you want to build a smaller system.

The processor slots in at the top of the board, and memory sockets are found alongside. The middle is dominated by PCI-Express x16 slots, one of which is used for the graphics card, and most also have a combination of PCI-Express x1 and PCI slots. The right-hand side houses SATA ports for storage; the bottom edge serves up connectors for audio, power and I/O; and the top-left corner provides the back-panel connectors.

Amid all of this is the chipset – a crucial component that determines which features are included. There's a surprising amount of variation found here – some chipsets are low-end parts that lack features but appear on cheaper boards, while others include every bell and whistle.

Take chipsets available for Intel's LGA 1150 socket. The low-end H81 is restricted to two SATA 6Gbps ports and two USB 3 connectors, while the enthusiast Z97 supports six of each.

It's important to consider your other components when looking at motherboard slots provided by different motherboards. SSDs need SATA 6Gbps connectors, and machines with dual-graphics require at least two PCI-Express x16 slots with lots of bandwidth. Most motherboards support 32GB of memory, which is enough for almost everyone – but check if you need more.

Think about the software, too. Most BIOS applications have been replaced by UEFI software, which adds better graphics and mouse control. If you want to overclock or tweak, it's worth investigating – if it's easy to use and has plenty of options, it makes life simpler.

Every one of these options needs to be considered against price – and the type of PC you're trying to build. Boards range from less than £50 to more than £500, and it's pointless paying over the odds for features you won't use.

We've chosen an ASRock Z97 Pro4. Its £78 price is reasonable, and it doesn't lack features. The LGA 1150 socket and Z97 chipset ensure good compatibility and features, there's support for plenty of memory, and it's got a good mix of slots in the mid-board – there are options for dual-graphics and other expansion cards.

Always make sure your case not only looks good but can also fit everything inside with ease.

STORAGE AND MEMORY

Memory slots in beside the processor and temporarily stores critical files. Right now, the most popular type is DDR3, and that's what we'll be using – but DDR4, which is faster but more expensive, has begun to appear.

Picking memory isn't just about choosing between DDR3 and DDR4 – the speed and capacity is vital. Basic machines can get by with 4GB, but 8GB is the minimum for more intensive tasks. Pick memory that runs at 1,600MHz or higher for rapid performance – but the faster the better. Check your motherboard's support for different amounts and speeds before buying, and make sure you're running in dual-channel mode for best performance.

The storage market has split over the past few years, with hard disks and SSDs existing in tandem and coming with their own pros and cons. Hard disks are cheaper with higher capacities, but they're slower and less reliable. SSDs are faster and less prone to failure, but they're pricier and smaller.

It's worth using both in a PC if the budget allows. Most systems use SSDs as boot drives, so Windows and applications benefit from faster boot and load times, with a larger hard disk used for software and files that aren't so dependent on speed.

Picking a hard disk is easy – make sure it's got 64MB of cache and runs at 7,200rpm, and then choose your capacity. There's more to look for when buying an SSD – read and write speeds should be above 500MB/s and 300MB/s, and TRIM support is vital. Check for endurance, too – the higher rating the better. Finally, check that the motherboard has a SATA 6Gbps socket.

Our £699 machine deploys a 256GB Crucial MX100 SSD and a 1TB Western Digital hard disk. The former is a budget drive that's faster than any hard disk, and the latter is capacious. We've also chosen 8GB of 1,866MHz DDR3

SSDs are faster than traditional hard disks, but cost a fair bit more.

memory – that's plenty of capacity and speed.

A CASE IN POINT

The enclosure ties the rest of the rig together, and it's one of the key areas when it comes to making an aesthetic statement – but there's more to choosing than picking one that looks good. It's important to make sure a case is big enough for the components. We've picked an ATX board, so we've chosen a case that's compatible with this form factor – and that logic follows if you've chosen a Micro-ATX or Mini-ITX board, too.

That's not the only component with size considerations. If a PC has a large graphics card, make sure that its hulking frame fits – many enclosures have removable hard disk cages that facilitate large cards. And, talking of storage, count up your drives and make sure the case has enough bays – you need 2.5-inch bays for SSDs and 3.5-inch for hard disks. If you're using a chunky CPU cooler, check its height, because some rub against side panels.

Cable-routing and ease of building also play a part. Invest in a case with a sensible layout to make building painless. Keeping cables out of the way doesn't just look good, but it improves air-flow, too. Look for enclosures with removable front, side and top panels, cable-routing cut-outs and a motherboard tray.

Choose a meagre power supply and your system won't run – but choose too much and you'll be paying over the odds for abilities you won't use. Make sure you've got the right connectors, because it's no good buying a high-end graphics card and a PSU that can't connect. This is especially important for multi-GPU rigs, because some power supplies don't include four PCI power plugs. If your budget allows, it's worth opting for a modular PSU. These have connectors that can be added or removed, which allows more versatility. It's a boon for adding more hardware to a rig as well as keeping your cables tidy.

We've chosen Corsair's Carbide 200R for our system. It's affordable, at £40, and it's got every feature needed: ATX compatibility, plenty of room, a motherboard tray and cable-routing versatility. Its storage bays are perpendicular, which is convenient, and it looks great – matte black and subtle. It's also a mid-tower case, so it's not too big.

Our £35 power supply comes from EVGA. It's a 500W unit, which is ample for this system. It's not modular – the budget doesn't allow it – but it has got every connector we need.

The final total comes to £699.59, and it ticks most boxes; the Core i5 processor has enough power for high-end applications, and the R9 280X is similarly dominant – it'll run every top game in the near future. Elsewhere, there's enough memory, a capacious SSD, a large hard drive and a neat case, with a capable and future-proofed motherboard tying everything together.

These complementary components have all been chosen because they can be used to build a powerful and balanced PC. This build illustrates the benefits of careful component choice – picking parts that work well together while avoiding common pitfalls. Building a PC can be daunting, but a bit of careful planning can ensure that your next rig works to its full potential – rather than not working at all. ■

Boom or bust?

Our £699 system is an ideal mid-range PC, but it's easy to modify the specification if you want to spend a little less or splash out to make it better. That's true of any specification thanks to a host of easy upgrades and downgrades.

Several cheap components can improve a new PC. Wireless networking cards don't cost the earth and can take the hassle out of getting the system connected to the internet, and sound cards are another worthwhile addition – if you've got good speakers or high-quality headphones, they can take movies and games to the next level.

Our Core i5 processor runs at stock speed and uses the standard Intel cooler, but it's an unlocked chip that can run faster with overclocking. You'll need a beefier cooler – decent models start at around £20 – but it's possible to easily get the chip beyond 4GHz with just a few BIOS tweaks. You don't need a new cooler to overclock the graphics card, either – AMD's driver has all of the settings required, and the R9 280X has a decent amount of overclocking headroom.

Other upgrades aren't as expensive or as obvious as simply opting for a more expensive processor or graphics card.

If you'd like to save some cash, a handful of sensible downgrades can cut down the price of a PC without impacting too much on performance. Dropping down to a non-unlocked Intel Core i5 processor can save some cash without compromising stock speeds, which is handy if you're not bothered about overclocking. Core i3 parts are even cheaper – although they're understandably slower.

It's the same story with graphics. Cards such as AMD's Radeon R9 270 and 270X are both cheaper and both still have ample power for playing games across single screens.

If you've got lesser demands, you could save even more money and opt for an AMD APU. It's a processor that includes a low-end Radeon graphics core, and top models can handle mid-level computing assignments while also playing games at reasonable quality.

There's a combination of components to suit every budget.

ANATOMY OF A PROCESSOR

A DEEP DIVE INSIDE YOUR PC'S MOST COMPLEX BIT OF SILICON

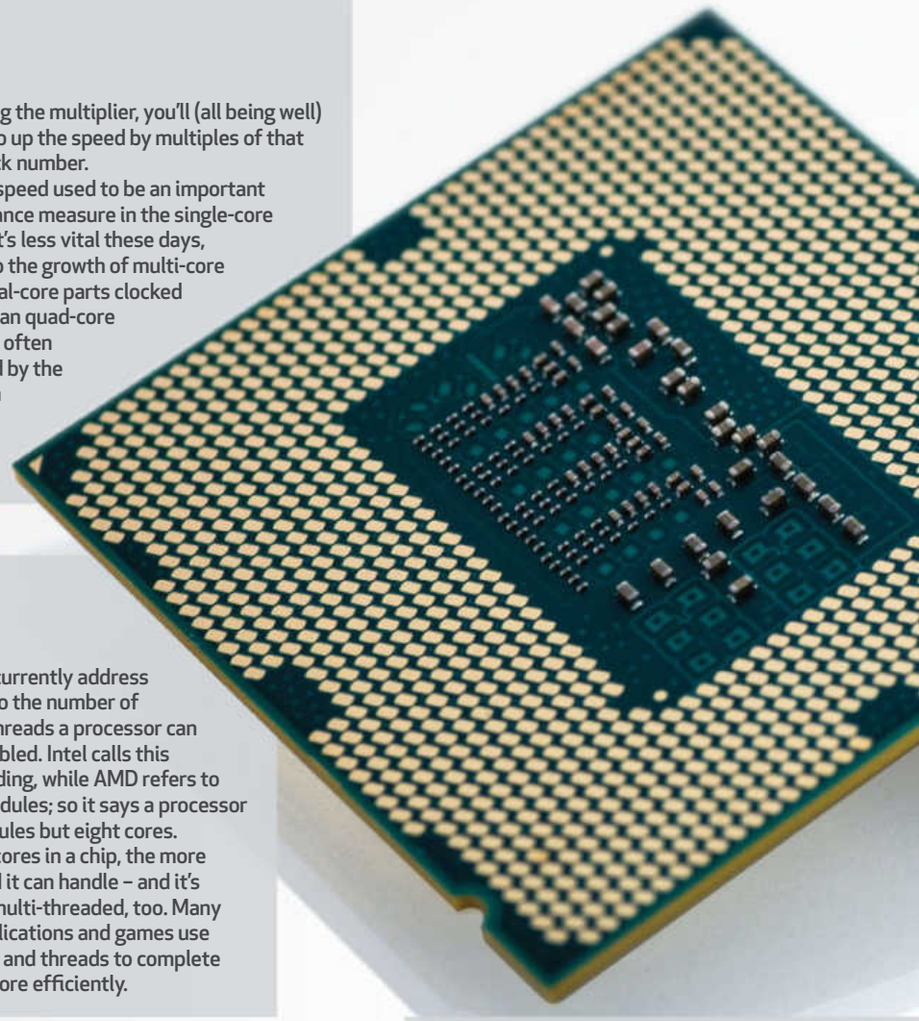
✓ Clock speed

Processors function, deep down, because of a tiny quartz crystal that vibrates at a particular speed. That speed – the clock speed – governs the pace at which the processor can execute instructions. The speed of this cycle also influences the speeds of other components inside a computer.

Hertz is used to measure clock speed, and we're dealing with large numbers. Intel's i-series CPUs use a 133MHz base clock, which represents 133,000,000 cycles per second.

That base clock speed combines with the multiplier to determine a CPU's final speed. This is the basis of overclocking; generally by increasing the multiplier, you'll (all being well) be able to up the speed by multiples of that base clock number.

Clock speed used to be an important performance measure in the single-core era, but it's less vital these days, thanks to the growth of multi-core chips; dual-core parts clocked higher than quad-core chips are often outpaced by the CPU with more cores.



✓ Core

Between two and six execution cores are used to construct most current desktop processors. These components are the central processing units that give the CPU its name, and they're self-contained parts of the chip that handle the major legwork.

Cores work independently, but they're aided by universal caches and memory controllers that manage the data that's flowing between the cores, the rest of the chip and the rest of the PC's components.

Modern chips often include multi-threaded operation, which means each core can concurrently address two tasks – so the number of application threads a processor can handle is doubled. Intel calls this Hyper-Threading, while AMD refers to cores and modules; so it says a processor has four modules but eight cores.

The more cores in a chip, the more of a workload it can handle – and it's better if it's multi-threaded, too. Many high-end applications and games use several cores and threads to complete their tasks more efficiently.

✓ Socket

This is the plastic tray that attaches the processor to the motherboard. Intel and AMD have their own systems, but both work in the same way – the socket holds the processor, with the chip clamped into position. That keeps the silicon secure, and it means a cooler can be attached over the top.

Intel processors lay on top of a flat surface, and the processor talks to the mobo through golden pads that link to the socket. The chips have notches that line up with the socket so installation has to be correctly orientated.

AMD chips are trickier. They interface with the motherboard using hundreds of tiny metal pins that line up with depressions on the socket. Those pines are fragile – one bent pin can render a CPU inoperable. AMD chips line up with an arrow on the socket.

✓ Cooling

Processors generate plenty of heat and need specialist hardware to keep cool enough to function properly. Every processor is sold with a standard Intel or AMD heatsink that's good enough to keep the chip cool as long as it's running at stock speeds.

These coolers are small and fitted using standard mechanisms – Intel coolers use push-pins to latch to the motherboard, while AMD heatsinks

Producing a processor

Processors are tiny, complex parts that process huge amounts of data, but their silicon is made from sand. Silicon is used to create wafers, and each holds the transistors that control electrical currents through the chip. These are tiny – millions fit on a pin head.

Every transistor goes through a process that involves ultra-violet light, etching and photo-resistant material, and they're blasted with chemical impurities called ions that change how the silicon conducts electricity. Copper fills tiny holes to connect the transistors, and entire wafers are dunked in a copper sulphate solution for electroplating. And, while the wafers look flat, they've often got 20 or more layers of complex circuitry built into them. The wafers are cut into small dies, which are the blocks of circuitry used to form each processor. Each die is much smaller than the physical chip that is placed into a PC; it's placed on top of a green base which contains the technology required for the processor to talk to the rest of the PC, and the die sits beneath the silver lid that dissipates heat.

AMD vs Intel

These companies dominate desktop processors, and it's vital to know the difference between their products.

Intel divides its chips into five families. At the low end there's Celeron and Pentium; Core i3 and Core i5 occupy the mid-range; and Core i7 dominates the high end. Prices range from £30 to more than £300. Low-end parts are slower, with fewer cores, while high-end chips have high speeds and four multi-threaded cores.

That's a broad church, but Intel's chips all use the same Haswell architecture and the same LGA 1150 socket.

AMD collects most desktop parts under its FX and A-Series brands. The former uses the AM3+ socket and sells mostly in the mid-range, with prices between £65 and £224 – the high ground has been conceded to Intel. A-Series chips have processing cores and Radeon graphics inside the same die, and use a different socket – FM2+. They're priced between £50 and £120, and provide good mid-range computing power for both applications and graphics.

"PROCESSORS ARE TINY, COMPLEX PARTS, BUT THEIR SILICON IS MADE FROM SAND"

Overclocking

This is the process to make a CPU run faster than Intel or AMD intend – and therefore eke more performance out of a processor.

The easiest way to overclock is to tweak a processor's multiplier; changing a chip's multiplier from 35 to 37 when it's got a base clock of 100MHz will increase the final speed from 3.5GHz to 3.7GHz. Further refinements can be made by tweaking the base clock, so you don't have to increase speed in increments of 100MHz.

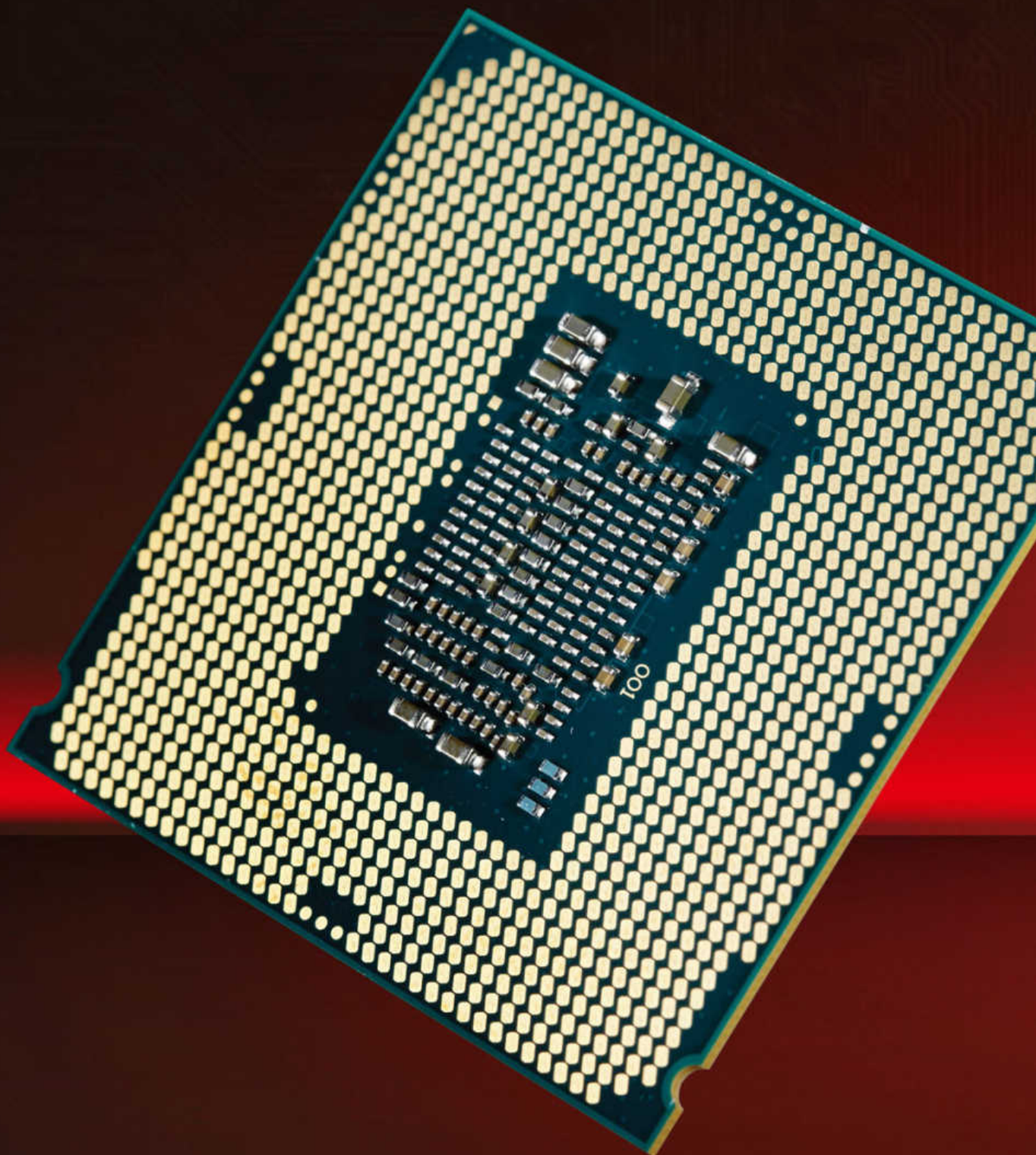
Dramatic overclocks require more electricity to function smoothly, so a higher voltage is often required to ensure that the chip runs stably at its new higher speed. More electricity and higher speeds will also increase the heat generated by the chip.

Overclocking is risky, and can void your processor's warranty. The increased electrical demands can also shorten a processor's life, or break it altogether – so think carefully before taking the plunge.

deploy a couple of hooks and a clasping metal arm.

Third-party coolers come in a range of different guises. Some air-cooled units are large and have slow-spinning fans so they run quietly, and others are even bigger and have no fans at all – ideal for building a passive PC. Other beefy air-cooled models are designed to chill high-end chips that run hotter because of overclocking.

Water-cooling is easier than ever thanks to the availability of pre-built units, and these fulfil the same role as high-end air-coolers – they're only really ideal if you have a high-end processor that will run overclocked.



Skylake Deep Dive

Intel's latest CPU architecture offers new power and opportunities

Well, here you have it folks. Skylake hath cometh to the people, and with it comes the absolute pinnacle of Intel's micro-processing technology. Let's just forget about Broadwell. Its short life time has been invaluable to us PC enthusiasts, but alas, it was never meant to be.

Taking us from that blasted 22nm architecture down to 14nm was an incredible feat. But it was too little, too late. Ultimately, the little chip paid the price, doomed to retire to an early death. A victim of its own architecture's difficult production methods.

Broadwell's glorious sacrifice, however, has given us one phenomenal gem – Skylake. If the X99 chipset and Haswell-E was the premium-grade reboot that PC enthusiasts needed, it's safe to say that Z170 and Skylake is about to do the same for the rest of us lowly four-core lovers. And let's face it, we've sorely needed it.

The last three generations of Intel CPUs have hardly seen a vast improvement over the original Sandy Bridge chips, and it's about time we were given CPUs that mopped the floor with that dusty old dog. Yes, Intel's cores may generally run rings around the competition when it comes to compute performance, but a 5 per cent performance increase and 10 per cent power reduction, year after year, just isn't exciting enough to warrant tattooing the Intel logo on the inside of our thighs. Not just yet.

Regardless of how it likes to name its early morning glow chipsets, Intel needs to knock this one out of the park. And although it's pretty much cemented itself in the world of enthusiast-grade CPUs, another 5 per cent performance boost just isn't that interesting, especially when most games currently struggle to utilise anything more than four cores anyway. Hell, we'd still recommend the i5-2500K if it was still available for sale.

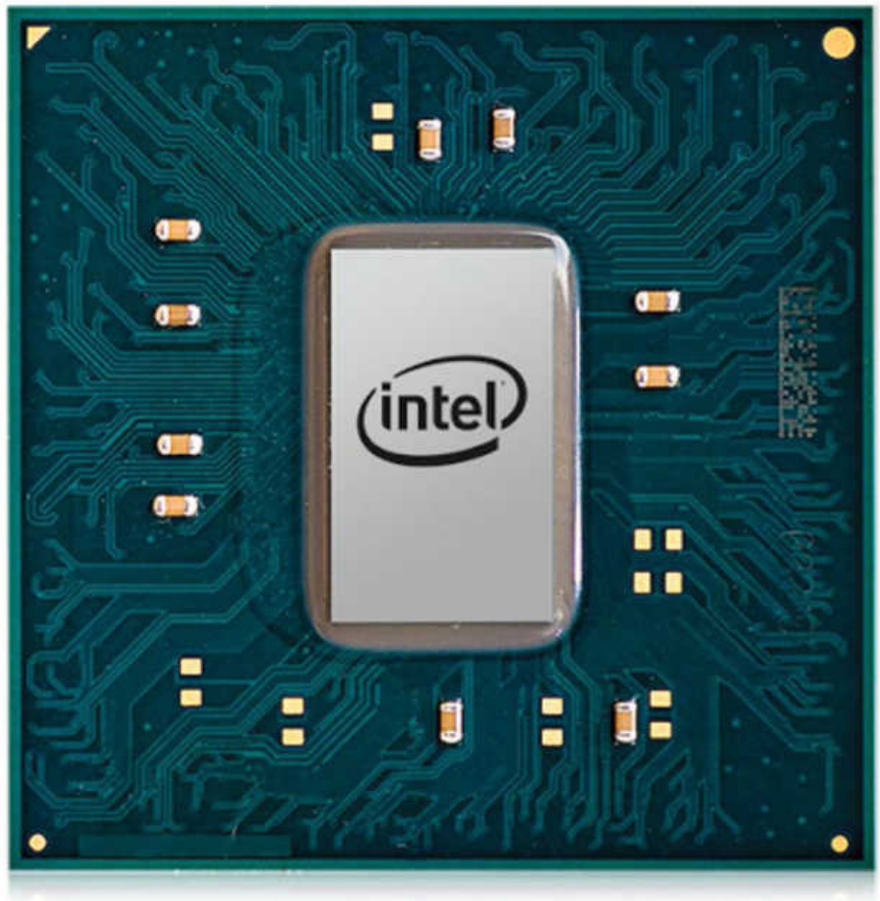
So what was it that kept Intel behind for so long? What do these chips represent to us? And what shiny new features will it bring to the table? Read on to find out what we discover in our in-depth report.

Skylake and the Z170 Chipset

Let's start with the basics. At this point, we have the Intel Core i5-6600K and the Core i7-6700K – the premium overclocking CPUs for the enthusiast users. These are the flagship models of Intel's consumer brand. Processors that, by their very nature, are designed to be pushed to the limits in the hunt for number-crunching, benchmark-rendering, overclocking perfection.

But what does Skylake bring to the table that Haswell didn't? Well, a 14nm processor for starters. Similar to the now-redundant Broadwell, yet a lot more promising. Intel has dropped the FIVR (Fully Integrated Voltage Regulator) from the CPU die and left voltage control entirely down to the motherboard manufacturers. This allows aftermarket partners to control how they supply power to each individual voltage controller located onboard the chip. What's exciting about this is how much variance we may start to see in the motherboard market once again. It's an area where, for a long time, it's been very difficult to differentiate between or even justify the cost of a £300 board over a £100 one. It might make choosing your motherboard about more than just buying the prettiest one for your budget. And that's fantastic, especially for competition's sake.

On top of all this loveliness, the Z170 chipset has a vastly expanded array of storage options – including Intel's new U.2 PCI Express connector, an additional 12 PCIe lanes to allow greater performance when running NVMe, and PCIe M.2 drives (an upgrade from gen2 to gen3). There's also continued support for six SATA 6Gb/s devices, up to 10 USB 3.0 ports and 14 USB 2.0 ports. Rather surprisingly, however, there isn't any native support for USB 3.1 (both Type A and Type C). Intel has stated that it's banking on Thunderbolt 3 being the more appealing solution to this particular platform. Although this seems a little short-sighted going forwards, only time will tell whether that will hold true or not. Who knows, maybe 3D Xpoint memory sticks will be powered by Thunderbolt and Intel will become our silicon overlord.



Hello Z170, aren't you a pretty little thing?

MEMORY MUSCLE

But the biggest and most exciting feature by far is the support for DDR4 RAM, the final advancement beyond the limited 2,400MHz DDR3 band. Z170 motherboards will support up to 64GB of memory, from 2,400MHz all the way up to 4,000MHz and beyond, advancing the ageing platform far past that of its Broadwell and Haswell cousins.

But don't fret if DDR4 prices are still a little too steep, and you have a few DDR3L RAM sticks kicking about, Skylake is backwards compatible. Albeit only with the low-voltage economy version, as opposed to the last platform's DDR3 offerings. That means that if you'd rather just use a DDR3L-enabled motherboard, you can do just that. But saying that, these boards do seem to be few and far between. The only manufacturer we know of that has boards with this feature for the foreseeable future is Biostar, a company that didn't exactly score very highly in recent reviews. Perhaps wait a little while for more to crop up.

If you're dipping into the funds to build a new rig, you really should be looking at DDR4. Prices have dropped by roughly half since they were launched in October last year, which means you're only paying around £20 extra for the same capacity of RAM at a far higher frequency than you once were.

Still not interested? Do you

SPECIFICATIONS

	Intel Core i7-6700K	Intel Core i7-4790K
Lithography	**14nm**	**22nm**
Frequency	4GHz (Turbo to 4.2GHz)	4GHz (Turbo to 4.4GHz)
Cores/threads	4/8	4/8
Cache	8MB	8MB
TDP	91W	88W
DDR support	DDR4/DDR3L – 64GB Max	DDR3/DDR3L – 32GB Max
PCIe configuration	1x 16, 2x 8, 1x 8, 2x 4 – Gen3	1x 16, 2x 8, 1x 8, 2x 4 – Gen3
Intel graphics	Intel HD Graphics 530	Intel HD Graphics 4600

consider yourself a bit of a speed freak, but memory just doesn't float your boat? Well, ladies and gents, we have one last nugget of juicy information for you – that's the inclusion of PCIe Raid 0, 1 and 5 support, allowing end users to RAID multiple NVMe drives together.

This has the potential to increase transfer read and write speeds all the way up to 3,500MB/s and beyond, approximately six times faster than your traditional SSD.

SPECIFICATIONS

	Z170 Chipset	Z97 Chipset
PCIe lanes	20 lanes Gen3.0	8 Lanes Gen2.0
SATA connectivity	6x SATA Ports / eSATA	6x SATA Ports / eSATA
USB support	10x USB 3.0 / 14x USB 2.0	6x USB 3.0 / 8 USB 2.0
Ethernet	10/100/1000 MAC	10/100/1000 MAC

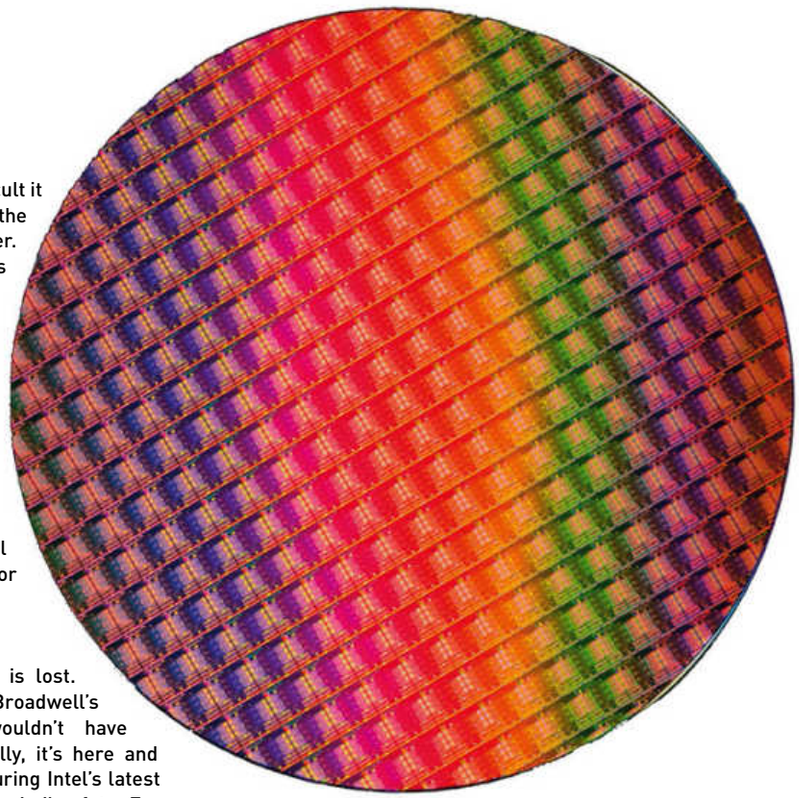
A New Architecture

Skylake's new architecture has been painstakingly woven from Intel's manufacturing plants and engineering genius. Having to drop Broadwell, even just to make its production deadlines, Skylake is the first widely available 14nm CPU microarchitecture.

It's a chip that's situated in the brand-spanking new 1151 socket (yes, one whole extra pin), alongside the Z170 chipset. Although not the consumer's first access to a 14nm chip, it'll be the most commonly sought-after processor line going forward, the go-to buy for us PC enthusiasts, overclockers and system builders looking for the best mid-range processors for our towers of power.

To build a processor like Skylake, you have to start from the ground up, and that's with the silicon. Essentially, a wafer-thin slice of computing crystalline goodness, silicon provides the basis for what the CPU will become, before it's cut out and embedded into the CPU superstructure that we're all so familiar with. Utilising a 193nm ArF lithography (basically a high-powered laser), Intel has to etch in all of the details for each and every processor, from each transistor upwards, essentially crafting every detail that makes a CPU a CPU.

The difficulty lies in the lithography itself. The laser in its most minute form is 193nm wide. To put that into perspective, the width of a human hair is 75,000nm across. So, to get that tiny beam of light small enough to even create one single transistor, it's necessary to utilise a variety of different technologies and optics to split the beam into even more ridiculous molecular sizes without necessarily losing any of the additional power that comes from the original beam. The smaller you go, the more difficult it becomes to split the laser down further. Ultimately, this is why it's taken Intel so long to go from the 22nm die size to 14nm, and thus why Broadwell has had such a brief (and rather unexciting) shelf life. We can only hope that this will not be the case for the 10nm chips.



This wafer is probably worth quite a bit.

KIT CRAZY

But alas, not all is lost. If it wasn't for Broadwell's sacrifice, we wouldn't have Skylake. Thankfully, it's here and on schedule, ensuring Intel's latest flagship dodged a similar fate. For release dates we can only speculate at this point, but rumour has it the full desktop lineup should be available by the end of this year, with mobile laptop processors making it to market by early 2016. Again, speculation and rumour on our part.

DDR4 memory is a crucial part of Intel's marketing strategy here. Although it's the next natural progression, the launch price was more than enough to put most people off their dinner. Fortunately, kits have been around since October 2014 and have slowly dropped in price since then with the launch of the extreme edition processors.

> The most exciting feature is the support for DDR4, the first advancement beyond 2,400MHz DDR3.

With Skylake's release (and dual-channel support) comes a wide variety of dual-channel kits at almost a comparable price point to DDR3. If you're still unsure what memory to choose, however, don't worry. Intel has you covered. Memory kits from the likes of Crucial, Corsair, G. Skill, Patriot, Kingston and Adata have all been approved by Intel, just to keep you safe of mind.

The Z170 motherboards, on the other hand, have been making the rounds for quite some time now, debuting with a wide variety of manufacturers showing off their long-awaited products at Computex, back in June. And man, do they look good! Most mainstream board partners have had these things ready since last Christmas (or thereabouts), so if you must have the latest hardware, or are thinking it's time for an upgrade, you'll be more than spoilt for choice.

DirectX 12 could well be a game changer, literally.

Power and Performance

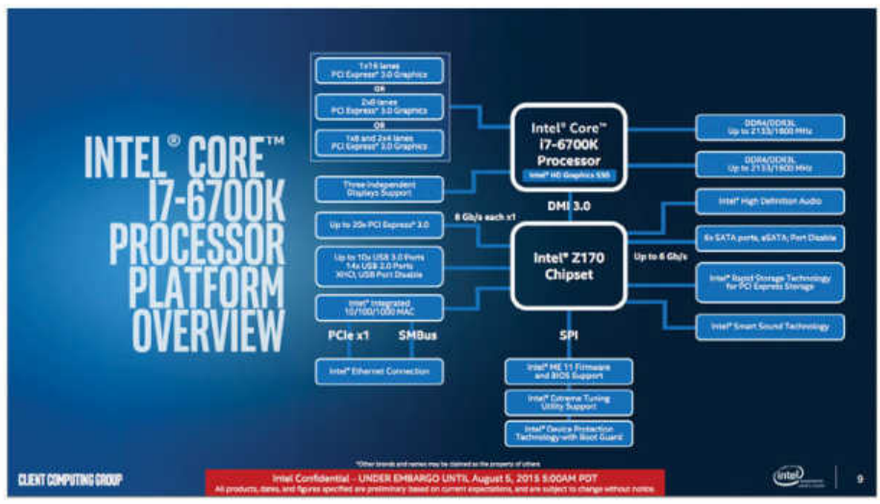
So, how does Skylake actually perform? Well, it isn't the absolute be-all-and-end-all of chip advancements. If you're only one generation behind, with Devil's Canyon, you'll only see around a 10–15 per cent improvement in benchmarks and rendering times, clock for clock.

In Cinebench, we saw an outright 11 per cent increase in performance over Intel's Core i7-4790K. Not too shabby to say the least, but not exactly beyond the realms of what we expected.

What is interesting is how far we can push the powerful four core. Skylake's overclocking potential is well documented as being far greater than that of its last three predecessors. And once we cranked our chip all the way up to 4.8GHz (a conservative clock, admittedly), we actually managed to push this core to perform just a little under that of an i7-5820K extreme edition processor at stock. Interested? You should be. It's certainly not impossible to get this processor even higher than that. Reports have come in of people clocking 5.2GHz on air alone, all dependent on the motherboard more so than ever. In fact, we managed to achieve these benchmarks on an entry-level £100 Asus motherboard.

All in all, this chip provides us with a very unique insight into what the 14nm processor series can do. But let's cut to the chase. Why is 11 per cent good? Is it really worth it? Well, consider it this way. If it's 10 per cent better than an i7-4790K, it'll be roughly 20 per cent better than a 4770K, and 30 per cent better than a 3770K, and so on.

If you're still stuck on the ever-faithful Sandy Bridge architecture [like some of our writers here are... *cough*], then this might be the perfect time for you to upgrade that CPU and take advantage of all of those additional chipset features and processing power.



With features galore, it could be time for an upgrade.

EFFICIENCY DRIVE

When it comes to literal power consumption, Skylake stands head and shoulders above the rest. We decided to build a basic test system to give the new girl a run for her money. It consisted of an Nvidia GeForce GTX 980, four sticks of Kingston HyperX memory, one 240GB Samsung Evo and a more traditional 2TB Seagate something or other. Under load (Prime 95 & Furmark), the rig pulled a total of 340W from the wall, utilising only half of the 750W power supply we had it running on. If nothing else, these chips will be fantastic for small form-factor builds and Steam Machines. Hell, if you really wanted to, you could run SLI on a 750W power supply with little-to-no worries at all.

The biggest area of improvement for Intel has been in the integrated graphics department. That may not mean much for those of you buying into the K-line processors, as you'll probably also be investing in a dedicated GPU. However, utilising DirectX 12 to leverage the CPU effectively could improve frame rates considerably in games. That may not be so beneficial for Twitch and streaming enthusiasts, but it harks back to what AMD was trying to implement with its Mantle API, allowing Intel to carefully leverage the processing power for what computational tasks each core is better suited to handling.

Overclocking Potential

Inherently, this generation of chips is vastly different to Haswell and the Devil's Canyon remit that we received last year. Primarily, this is down to Intel's decision to remove the FIVR from the chip design.

The FIVR, or Fully Integrated Voltage Regulator, was a component piece of the CPU found in any previous generation of Intel processor. Its sole purpose was to regulate and control the overall voltage that went directly into each part of the compute portion of the CPU, such as the DRAM controller, and the VCore. By removing this, Intel has handed voltage control to the motherboard manufacturers. This means that, instead of a standardised level of voltage operating across the entire platform, it's now possible for board partners to implement specific voltages for each of those compute portions we mentioned earlier.

But are they cooler than Devil's Canyon? Skylake is quite cold, no doubt partly due to the removal of the FIVR we mentioned earlier. This enables you to ramp up the core clock frequency considerably, without worrying about thermally throttling the chip. But you're still going to need an aftermarket cooler for the majority of your overclocking attempts, as it will provide a great deal more headroom when trying to achieve those higher clockspeeds.

The Core i7 still rules the roost when it comes to overclocking potential.

BASE CLOCK BATTLES

In our testing, we found the Core i7-6700K to be a solid 3–4°C cooler than the Devil's Canyon refresh under load. And although Intel has promised to reimplement the FIVR, this doesn't seem likely to happen until the iteration after Kaby Lake, known as Ice Lake. All in all though, we're not too sure whether losing the FIVR is a bad thing or not.

Another change that's come with Skylake is the ability to alter the base clock frequency in 1MHz increments. The base clock frequencies are currently 100/125/166MHz on Devil's Canyon. However, Skylake scraps the ratio-based system entirely, allowing higher overall overclocks for those willing to eke out every millimetre of power from their otherwise beastly new CPU.

It's important to note, however, that you'll need to adjust the core ratio to coincide with what target clockspeed you're attempting to achieve. For example, if you change the base clock to 300MHz and leave the core ratio at default, you'll end up trying to achieve a 12GHz overclock. Which, we think, is theoretically impossible at this point in time.

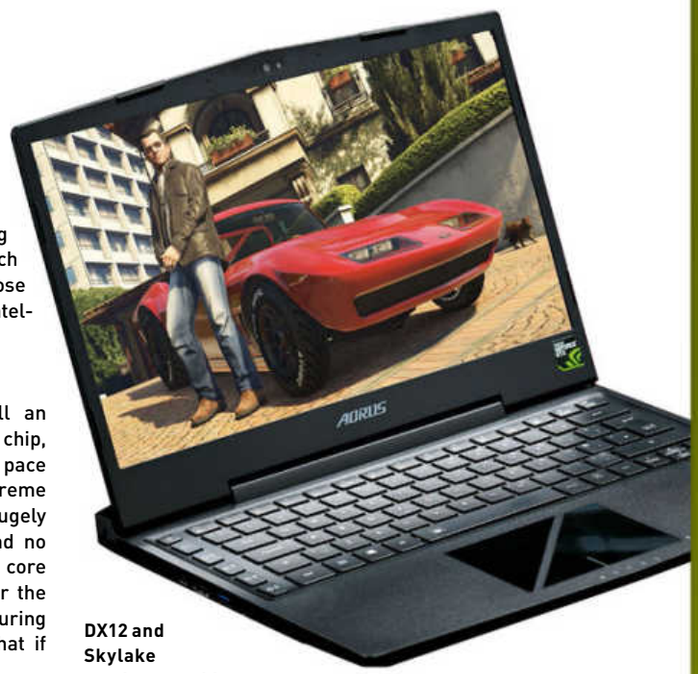
Conclusion

So, what does Skylake mean to PC enthusiasts like us? Well, probably that it's finally time for an upgrade, for starters. Intel is still top dog when it comes to single and multi-threaded processor performance, and this looks unlikely to change any time soon.

Hopefully, AMD will bring back some competition via the Zen cores, but who knows how far off that will be. What these K-series processors have shown us, however, is that Intel's famously weak integrated graphical horsepower has been increased considerably compared to the last series. And, although those running the overclockable chips are hardly likely to be utilising integrated graphics alone, this does give us a good insight into the capability of the more mainstream chips being released later this year, which is especially interesting for those running laptops and other Intel-powered mobile devices.

PROMISING FUTURE

As much as Skylake is still an incredibly competitive chip, however, it still doesn't hold pace with Haswell-E. The extreme edition processors benefit hugely from the additional cores, and no amount of Hyperthreading or core performance will beat that for the time being. What we did find during our testing of Skylake was that if you overclocked the CPU up to 5GHz, it actually matched benchmark performance with that of the entry-level model i7-5820K at stock. For an enthusiast-grade chip, that's one hell of an achievement.



DX12 and Skylake gaming-capable laptops anyone?

Over the next few years, we'll no doubt see some incredible advancements when it comes to computational power. If Intel keeps this progress up, 10nm processors might not be as far away as many may think. And with 3D Xpoint landing sometime next year, the next phase may change how we look at the world entirely. It's an exciting time to be a tech enthusiast, that's for sure.

Intel has rebranded the packaging, just to entice you that little bit more.

ANATOMY OF A GRAPHICS CARD

WE'VE DECODED THE GRAPHICS CARD TO FIND OUT WHAT MAKES TOP GAMES TICK

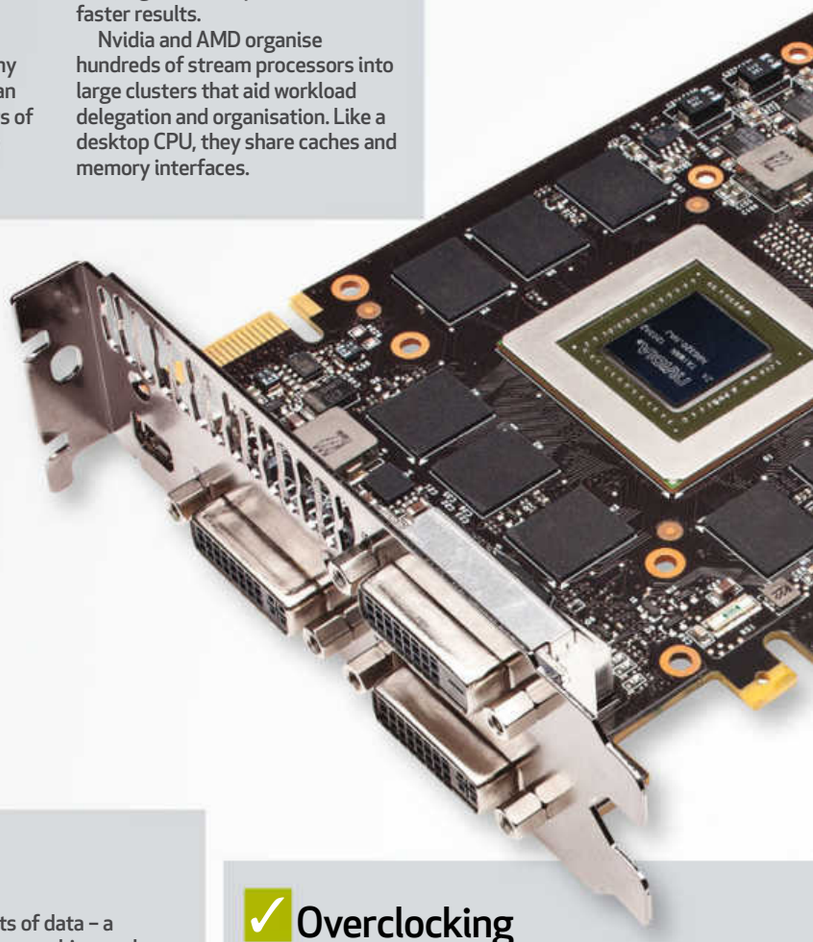
✓ The core

The processing core functions in a similar manner to a PC's processor – it uses clock cycles and cores, and speed is measured in hertz. The specialised demands of this hardware means a graphics processing unit, or GPU, is built in a different way.

The mathematical demands of a GPU mean that high-end graphics cards have more transistors than high-end processors; an Nvidia GeForce GTX 780, for instance, has seven billion, which is more than four times the number included in Intel's Core i7-4770K.

Transistors form stream processors, which function as tiny processing cores. These cores can be used to produce specific parts of images, and graphics cards have hundreds – or, at the high end, thousands. The huge numbers help with the intensely parallelised workloads handled by GPUs and, as ever, higher clock speeds mean faster results.

Nvidia and AMD organise hundreds of stream processors into large clusters that aid workload delegation and organisation. Like a desktop CPU, they share caches and memory interfaces.



✓ The fabrication process

This refers to the method that wafers – and, therefore, the dies that create graphics cores – are produced. AMD and Nvidia contract external firms such as TSMC and GlobalFoundries to build these, and they're always pushing to build wafers with smaller transistors.

Transistor size is measured in nanometres, and reducing this number has several advantages. If transistors are smaller, more can be packed into a graphics card's die – which means more raw processing horsepower.

Smaller transistors have improved thermal efficiency, which means higher clock speeds – and, again, more power.

It's a constant challenge to produce smaller transistors consistently. Nvidia's forthcoming Pascal GPU will be manufactured on a 16nm scale, which is the next leap in size.

✓ Memory

Graphics cards are powerful enough that they need dedicated memory – and, as usual, the more and the faster the better. It's used to temporarily store the data that's been generated by the graphics card before it's used to render frames on-screen.

Current graphics cards use GDDR5 memory, which is based on the DDR3 memory used in desktop PCs and laptops. Graphics memory is configured differently to DDR3, with higher bandwidth at the expense of latency in order to handle consistent, large amounts of data – a challenge encountered by graphics cards.

Even the cheapest GPU will be accompanied by 2GB of GDDR5, but that's the bare minimum for playing top-tier games. Mid-range cards are now often sold with 3GB or 4GB, and top-end cards sometimes have more.

Make sure a new graphics card has enough memory and at a high enough speed to last the course, because it can't be upgraded, unlike RAM inside a desktop PC.

✓ Overclocking

Graphics cards use the same basic components as processors, and they're even easier to overclock than their socketed stablemates.

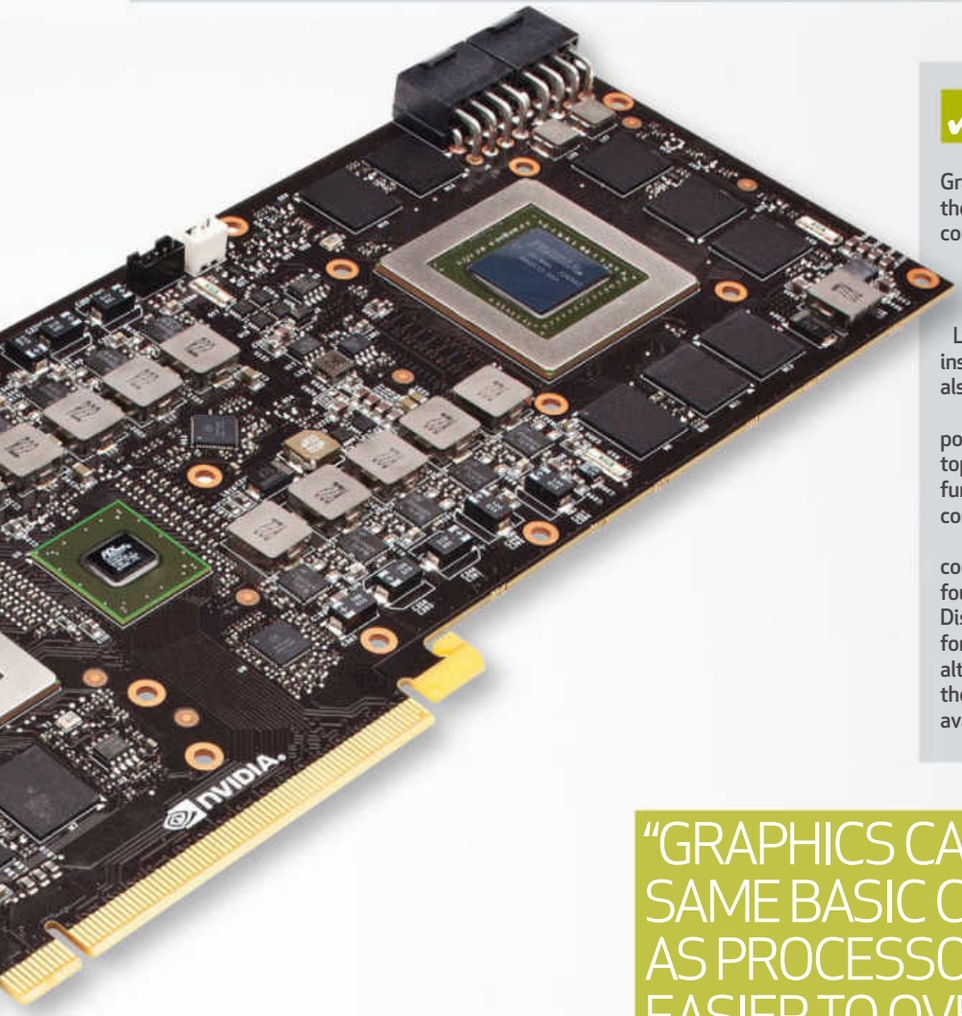
For starters, GPU overclocking doesn't require fiddling in the BIOS. It can be done in software, with some options available in AMD and Nvidia's drivers, and other third-party tools that can improve speeds by clicking a button.

Graphics overclocking involves tweaking the core and memory clocks, and sometimes the

✓ Slots and display connections

A graphics card interfaces with the rest of a PC via a PCI Express slot, which can cope with the kind of demanding data transfers required by graphics cards. Motherboards have PCI Express sockets in a variety of sizes, and most graphics cards use x16 slots – the largest. These fall into two standards: PCI Express 2.0 and 3.0. The latter is newer and has ample bandwidth for even the most powerful cards, where 2.0 might struggle.

Also check whether a PCI Express slot is able to use its full bandwidth. Most motherboards have one PCI Express x16 slot that runs in x16 mode, but secondary slots are often restricted to just x8 or x4 modes – so they're only able to use a half or a quarter of their potential bandwidth – due to chipset restrictions.



✓ Physical challenges

Graphics card installation isn't as simple as pushing the card into a slot – the card needs to have the right connections, and the case needs to be large enough.

Powerful cards generate more heat, which means larger and more sophisticated cooling systems are required to keep the core chilled. Larger heatsinks are sometimes too long to fit inside smaller cases, and double-width coolers can also block motherboard slots below the card.

That's not the only physical consideration. More powerful cards require more electricity, with some top chips needing two eight-pin power plugs to function. Most power supplies come with these connections, but it's worth checking in advance.

Every graphics card has a variety of outputs that connect to monitors. The most common connections found on modern cards are HDMI, DVI and DisplayPort – the latter is the newest, and is useful for connecting extremely high-resolution displays, although the likes of USB 3.1 may one day supercede these specific formats; the sheer bandwidth available makes it a very strong option.

"GRAPHICS CARDS USE THE SAME BASIC COMPONENTS AS PROCESSORS, AND ARE EASIER TO OVERCLOCK"

boost limits – so cards can dynamically overclock to even higher speeds.

The GPU equivalent of upping the voltage involves raising the card's power limit, which is usually as simple as raising a slider.

It's easy to overclock a graphics card but, as with desktop processors, it is a risky business. If damage is caused to the card because of overclocking, it can void its warranty – as well as break the card.

✓ AMD and Nvidia decoded

AMD and Nvidia are the big players in graphics, with both firms battling for GPU supremacy. Both companies use different naming schemes. Nvidia's cards are all prefixed with 'GeForce', and top-end cards also use 'GTX'; low-end products only use 'GT'. Beyond that, the bigger the number the better – cards such as the GTX 750 and 760 are mid-range products, with the GTX 980 and Titan at the high end. Cards with the 'Ti' suffix are slightly more powerful versions of their origin card.

AMD's Radeon naming scheme has recently changed. Now its cards are divided into three groups: R5 cards are entry-level products; R7-branded parts sit in the mid-range; and high-end chips are denoted by the R9 prefix. Beyond that, it's a similar story to Nvidia – the bigger the number, the better the card, and the higher the price. Cards with an X attached to their names are more powerful.

The companies tend to follow each other closely when it comes to price and performance – it's handy to look for overclocked cards and game bundles to help differentiate between the two when buying a new card. ■

The Future of the GPU

It could be the perfect time to upgrade your current graphics card, but what do you need to prepare for the GPU future?

THE GRAPHICS CARD is the component most responsible for PC gaming performance. Above everything else in your PC. You could have the most powerful, £800 octo-core Haswell-E CPU in your rig, but if you've got a weedy GPU backing it up, you're never going to be hitting the graphical heights that today's PC games deserve.

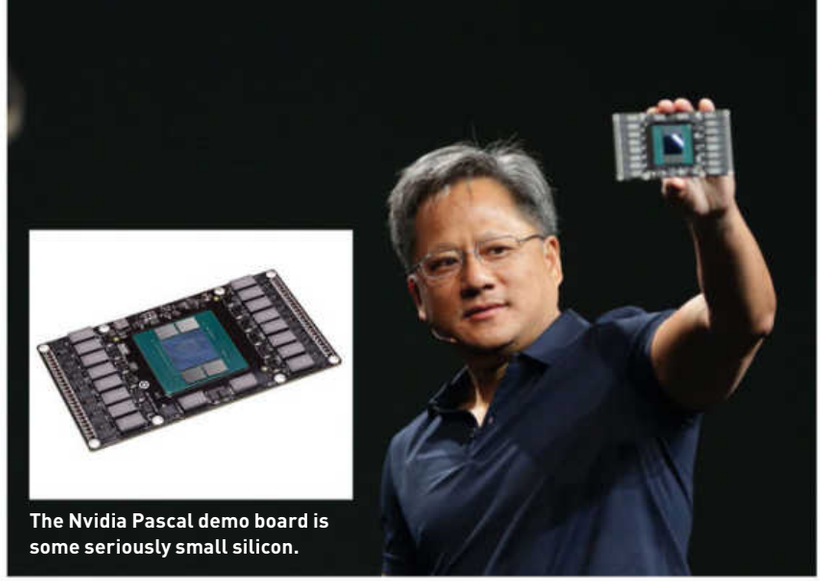
And it's a great time to buy a new graphics card right now. Both the leading lights of GPU development – Nvidia and AMD – have recently released brand new graphics card lineups, with high-end, ultra-enthusiast GPUs and super-efficient, lower-end offerings. And by the way, for ultra-enthusiast, read: eye-wateringly 'wtf-how-much?!' expensive.

While Nvidia has had it pretty much all its own way since the GTX 980 was released almost a year ago, AMD has finally responded with a slew of new – and some not so new – GPUs to try and put it back in the game. Correspondingly, Nvidia has updated its range and dropped the prices here and there. Who wins? We all do, of course. You can now go and bag yourself a quality, high-end graphics card for some pretty reasonable sums of money. Which is why this month we've got them all into one room for a GPU battle royale.

If this is the state of play in the graphics card market right now though, what does the future hold for this pedigree racehorse of components? Are we likely to have genuinely affordable, genuinely capable GPUs delivering the 4K feels on the next generation of high-resolution gaming monitors? And is the end nigh for the classic peripheral component interconnect express?

Both Nvidia and AMD are set for big new GPU architectures on incredibly tiny production processes in the next year, having both missed out on the bonanza that 20nm lithography was meant to offer. It's set to be a very intriguing time for the not-so-humble GPU then, and with the rise in screen resolution and the burgeoning VR industry's insatiable thirst for GPU power, it needs to be. Let's do some digging and see if we can figure it out what's going on...

Even the Titan X will look weedy against the 16 billion transistors of Pascal.



The Nvidia Pascal demo board is some seriously small silicon.

Before we go too far into a future filled with high-bandwidth memory (HBM), new component interconnects and new GPU architectures, there are still a few holes to be plugged in AMD and Nvidia's respective graphics card lineups.

Scheduled to arrive very soon, possibly by the time you read this, is Nvidia's replacement for the GTX 750 Ti – inevitably named the GTX 950 Ti. The GTX 750 Ti was the first Maxwell-powered graphics card and it makes sense for it to now be refreshed with new silicon. It's more than likely to be sporting a slightly cropped version of the GM 206 GPU found in the current GTX 960.

Like the GTX 750 Ti before it, the GTX 950 Ti (probably set to release alongside the GTX 950) should offer impressive levels of power efficiency combined with decent 1080p gaming performance, too.

To counter it, AMD is looking to try and spoil the low-end GPU party with its own Radeon 370X, a Trinidad GPU-powered card aiming squarely at the same price point as the GTX 950 Ti. It will essentially be using the same Pitcairn GPU that AMD filled the R9 270X out with, and it will be interesting to see who comes out on top in the battle at the bottom of the market.

There are also rumours that AMD is hard at work putting together a full range of HBM-supported graphics cards to follow the Fiji model used in the Fury cards. Whether that will be as part of an interim refresh of the current chips isn't known, but that's probably unlikely. We expect the current lineup to last until the next AMD GPU architecture drops next year.

BUT WHAT'S NEXT?

With the Maxwell GPU architecture having been around for a good long while now – since early 2014 with the GTX 750 Ti and from late 2014 with the full-fat GTX 980 cores – it's time to start thinking about what's coming next.

The next generation of graphics cards from both Nvidia and AMD is going to see a major cut in the production process. This is the big news from the next round of GPU architecture updates, and also the reason for this current generation being something slightly different to what we originally expected.

> "Pascal will be the first Nvidia cards to offer 3D memory – it's set to use HBM 2.0 to achieve a purported 32GB max frame buffer."

When the two companies first started talking about their Maxwell and Pirate Islands GPU ranges, it was largely expected that these would be the first chips to tip up rocking the new 20nm production process. And it wasn't just us expecting that either – both the GPU makers thought they'd be making the move.

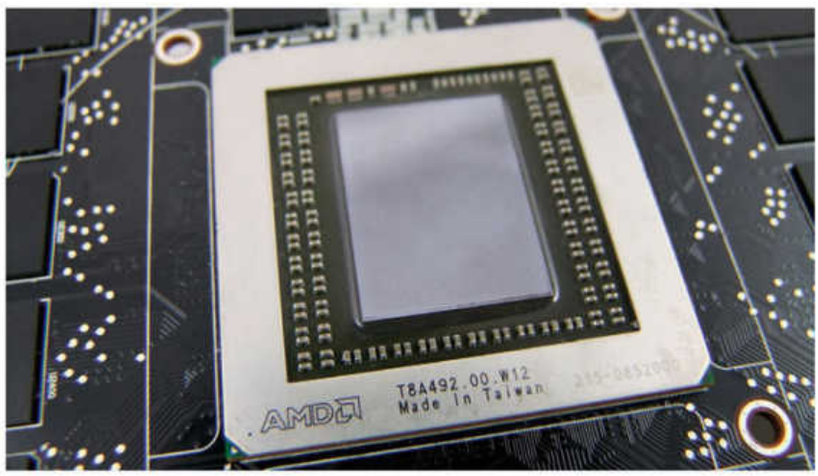
However, the 20nm process turned out to be a nightmare for the silicon makers to produce chips with at a consistent yield without losing a bunch to defective parts in the baking process. This made the whole 20nm lithography seriously expensive. Tied to the fact that it wasn't actually delivering much in the way of performance or efficiency gains, it's unsurprising that the switch wasn't deemed worth it.

So Nvidia and AMD have been stuck on the existing 28nm process for at least one generation longer than either really expected. Nvidia, however, seemed to see the writing on the wall, and, with the already-efficient Maxwell architecture, it was still able to deliver improved GPUs. AMD, on the other hand, has stuck with its existing architecture and simply piled more and more silicon into the design to boost performance.

But the new 2016 GPU architectures from AMD and Nvidia won't be on the 20nm process either. That ship has sailed and now we're expecting both companies to move their chip production process to the new 16nm FinFET (similar to Intel's Tri-Gate 3D transistors) lithography. This will allow far more transistors to be packed into the same, or smaller, die size and yield greater efficiency gains, too.

BLAISE OF GLORY

On the Nvidia side, we're looking at an architecture called Pascal – named after the French physicist Blaise Pascal – and the rumour that the successor to the full-fat GM 200 GPU could have as many as double the transistor count. That would



Sticking with a 28nm GCN chip requires some serious cooling.

The next step for AMD's GPUs is to drop to the 16nm lithography.

The upcoming GTX 950 Ti could well come passively cooled.

give it somewhere upwards of 16 billion transistors. That phrase needs to be read in your head one more time with Carl Sagan's wondrous tones.

The Pascal GPU will be the first of Nvidia's cards to offer 3D memory and is set to use the second generation HBM 2.0 to achieve the purported 32GB maximum frame buffer. One of the struggles with the current HBM tech used on AMD's Fiji cards is that it has a limit of 2Gb per DRAM die, making a maximum of 1GB in a stack, and only four memory stacks per GPU interposer. That's why the Fury cards have a slightly miserly, though speedy, 4GB frame buffer.

HBM 2.0 though is designed to massively boost that upper limit with a limit of 8Gb per die and stacks offering either four or eight dies piled on top of each other. That will give each stack a maximum of either 4GB or 8GB in capacity. With four of those HBM 2.0 stacks arrayed on the interposer around the GPU itself, you're looking at either 16GB or 32GB frame buffers, depending on the SKU.

Pascal is looking to unify its memory, too, making it available to both CPU and GPU. In traditional interfaces, that would introduce latency issues across the PCIe connection when communicating between CPU and GPU. But with Pascal, Nvidia is introducing a new interface called NVLink. On our PCs, however, NVLink-proper looks a while off (see "Is NVLink the end for PCIe?", to the right, for more on that).

AMD ADVANCES

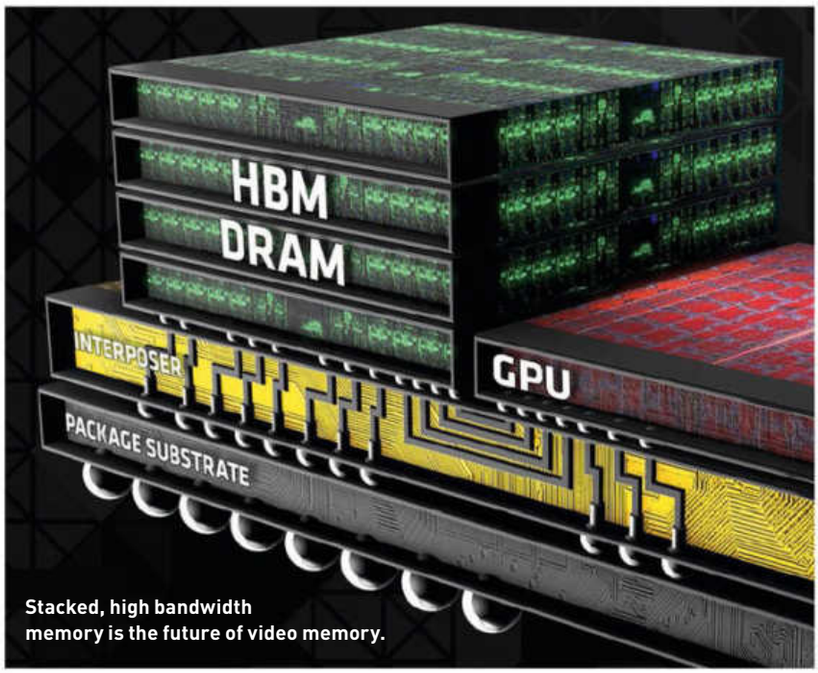
AMD's Arctic Islands architecture – also due in 2016 – could be AMD's first new GPU architecture since the inception of the Graphics Core Next design at the beginning of 2012. It has mentioned a doubling of the performance-per-watt efficiency of its high-performance range of GPUs.

It's unlikely to be too radical a departure from the current GCN architecture though, especially given mixing a new production process with a brand new architecture can be a recipe for disaster. Though that is also the route Nvidia is taking with Pascal...

What we do know is that the successor to the top Fiji GPU of today will have the Greenland codename and will sport the same second-gen memory architecture as the Nvidia cards – HBM 2.0. That will mean huge potential frame buffers all round. The Arctic Islands range will also utilise the 16nm FinFET technology, which is arguably how it's going to be able to nail the 2x perf-per-watt target that AMD has set itself.

With the introduction of the new lithography and the promise of high bandwidth memory being used throughout the GPU stack, we're pretty confident that Arctic Islands won't suffer from the same rebrand-a-thon woes that have somewhat blighted the current Southern Islands/ R300 series release.

All in all, 2016 is looking a seriously exciting year in terms of graphics cards. The efficiency gains from the 16nm lithography will keep things highly chilled in the mid-range, but also allow for some absolute monster GPUs at the top end. Hell, we could be looking towards 8K gaming by then, guys and gals.



Stacked, high bandwidth memory is the future of video memory.

NVLink is going to be used between GPUs on our desktops.

Is NVLink the end for PCIe?

ALONG WITH the announcement of the Pascal architecture, Nvidia CEO Jen-Hsun Huang also introduced the world to NVLink, an interconnect for its GPUs that could potentially offer between five and 12 times the bandwidth of the current PCIe 3.0 connection.

Nvidia's talking about NVLink offering DRAM-class speed and latency, which will allow for the use of Pascal's unified memory across the entire PC. It will also improve performance between GPUs, so multi-GPU systems could end up getting a far more linear scaling in terms of gaming speed.

As well as the NVLink connection on the GPU itself, it will also require dedicated silicon in the CPU if it wants to bypass the PCIe interface completely. From the outset though, that looks likely to be restricted to supercomputer-class high performance computing (HPC); Intel is unlikely to start dropping Nvidia silicon into its designs.

But if there's no path to the CPU, NVLink can just dedicate all its available bandwidth to GPU-to-GPU connections, which is what will potentially enable it to bear fruit in our gaming PCs.

Right now we're a fair way off saturating the available PCIe bandwidth on our rigs. The current interconnect is fine for our present-day needs, but boosting SLI scaling could be a real bonus. In terms of HPC applications, however, there are times when programs are doing large pro-level processing on the GPU – such as image processing for astronomy or seismic processing – and the PCIe interface becomes a serious bottleneck.

For our machines, that's not going to be a problem, and AMD shows no sign of wanting to shift interfaces either. We can't see PCIe going dodo any time soon, at least not in the next couple of years.

Nvidia GTX Titan X

Not winning this clash of cards

NVIDIA'S GTX TITAN X is the pinnacle of today's graphics card technology, a position it's likely to maintain until Pascal tips up, waving its 16nm transistors all up in the GM 200 GPU's silicon face. But that doesn't make it the best card around.

At launch, the £800 price tag seemed insanely, almost offensively, high. Sure, it was the first time we'd seen the much-vaunted GM 200 GPU appear in a form we could jam into our desktop machines, and it is most definitely head and shoulders above the GTX 980 in terms of gaming performance, but it didn't have the same feel as the original Titan.

It lacked the supercomputer, double-precision capabilities for a start, and we never warmed to the black shroud of the 'X' either. The big problem, however, is that card sitting nonchalantly to its right – the GTX 980 Ti.

It was always going to happen. GPU history has taught us that much. But the release of the GTX 980 Ti has rendered the Titan X almost entirely irrelevant. The higher clockspeeds of most iterations of its younger sibling made the difference between core count vanish, and often delivers the GTX 980 Ti a performance lead.

And yet, the Titan X is still almost £200 more expensive, only buying you an extra 6GB on top of the GTX 980 Ti's frame buffer. By the time you need 12GB of graphics memory, the next generation of mid-range GPU tech may well be making this ol' ultra enthusiast card look tired.

SPECIFICATIONS

GPU	GM 200
CUDA cores	3,072
Memory capacity	12GB GDDR5

VERDICT **7**

Nvidia GTX Titan X

TITAN Huge frame buffer; overclockable.

TITCH No double precision; doesn't offer value at super-expensive price.

£820, www.ebuyer.com

Inno3D iChill 980 Ti Black

Chilling with the fastest GPU

ANYTHING YOU CAN DO, I can do better, says Inno3D's liquid-chilled GTX 980 Ti, swishing its rubber-tubed tail in the Fury X's direction. This is one of the finest examples of the Titan-killing GTX 980 Ti and shows AMD a thing or two about high-end GPUs.

Rocking almost the same GM 200 GPU as the Titan X, the GTX 980 Ti is missing only 256 CUDA cores and a 6GB chunk of VRAM, but has the same number of ROPs and 336-bit memory bus. Coupled with that stonking GPU, Nvidia has let each manufacturer put their own stamp on the GTX 980 Ti, too. Most cards you see will be factory-boosted units with new cooling arrays bolted on.

That means cards like this Inno3D one here really put the Titan X in its place. It also sits well above AMD's R9 Fury X; its closest rival from the red side. The issue with factory-overclocked cards, however, is that they have a hefty price premium attached, though you can still get more affordable GTX 980 Ti's that give the Titan and Fury X-ers a bloody nose for well under £600. With this card you can get genuinely playable frame rates from the likes of *GTA V* and *Shadow of Mordor*, even at the most strenuous of 4K settings.

This still feels like a ludicrous amount of money to spend on a new graphics card, but for value, it beats the Titan X hands-down. The high-end 4K performance you get with this GPU makes it a mightily tempting proposition and a very aspirational card.

SPECIFICATIONS

GPU	GM 200
GCN cores	2,816
Memory capacity	6GB GDDR5

VERDICT **9**

Inno3D iChill GTX 980 Ti Black

CHILLING Super-speedy; cool; Titan-killer.

COLD FISH Still expensive; not much faster than other 980 Ti's.

£630, www.overclockers.co.uk

AMD Radeon R9 Fury X

Full of sound and fury

WE GENUINELY HAD HIGH HOPES for the Fiji GPU in the latest Pirate Islands range of flagship AMD graphics cards. And then the tantalising promise of the first sub-28nm GPU vanished along with the 20nm process it was supposed to use, leaving us with just the hopes that high bandwidth memory (HBM) might lift this new Radeon high enough to compete with Nvidia's finest.

The struggle with Fiji is that, to all intents and purposes, it represents very little advancement from the previous generation of Graphics Core Next chips. It's just got a lot more logic inside it. If that had been paired with the die-shrink, things might have been rosey. As it is, the 28nm GPU generates a lot of heat (note the water cooler on the vanilla reference board). Even with the huge 4,096 Radeon cores inside, it can't perform as well as the slightly more expensive reference GTX 980 Ti.

It has got the first generation of HBM in there – that's allowed for the smaller form factor, but seemingly little else at the top resolution. At 1440p and 1080p you get a nice uplift over the old Tahiti-powered R9 290X, but when you hit 4K, that 4GB frame buffer just runs out. Because of the limits of first-gen HBM, AMD could only fit 4GB onto the Fiji GPU.

With hugely detailed games such as *Middle-earth: Shadow of Mordor*, *Total War: Attila* and *GTA V* demanding well above that limit, the Fury X quickly bumps into its performance ceiling.

SPECIFICATIONS

GPU	Fiji XT
GCN cores	4,096
Memory capacity	4GB HBM

VERDICT 7

AMD Radeon R9 Fury X

XPERT Water cooled; next-gen memory.

FURIOUS Can't catch the GTX 980 Ti; only 4GB frame buffer; relatively expensive.

£510, www.ebuyer.com

Sapphire R9 Fury Tri-X

Fast and a little furious

SUCH IS THE WAY with AMD graphics cards – they will almost always arrive two-by-two. When AMD creates a class of GPU, it will generally offer a higher-end XT version and a slightly cut-down Pro version.

The R9 Fury then is the slightly cut-down Pro version of the Fiji XT in the Fury X. The Fiji Pro has 512 fewer Radeon cores than its bigger brother, and a 50MHz drop in base clock, but is happily sporting the same 4GB of HBM for a super-speed frame buffer. It's also around £100 cheaper than the Fury X.

Which leaves us scratching our heads. This Sapphire, Tri-X-cooled version of the Fury actually clocks just 10MHz behind the Fury X and yields almost identical gaming frame rates as the more expensive, water-cooled reference card. Yes, the air-cooled card inevitably runs hotter – by around 15 degrees - but when you're dropping only a few fps on average, but saving £100, it becomes a bit of a no-brainer.

It's still over £400 for effectively a third-tier graphics card, but it will deliver excellent gaming performance and, if you're not going 4K yet, will make your 1440p screen sing. The Fury also goes toe-to-toe with the 980, often taking a performance lead. That has led to some price drops on the older card though, so you can find great deals on the Nvidia side now. But when the price is close, we'd recommend staying with the more-advanced card that's rocking HBM if you're chasing a purchase.

SPECIFICATIONS

GPU	Fiji Pro
GCN cores	3,584
Memory capacity	4GB HBM

VERDICT 9

Sapphire Radeon R9 Fury Tri-X

TRUSTY Almost as quick as the Fury X; decent cooling.

TRIXSY Expensive; only just faster than 980.

£444, www.scan.co.uk

Palit GTX 980 JetStream

Bon anniversaire, old fella

IT SEEMS FUNNY TO THINK the GTX 980 is almost a year old. It doesn't seem that long since we first plugged the big Maxwell chip into our test rig and were blown away by the unprecedented mix of performance and efficiency.

Despite still being built of the same 28nm transistors as the Kepler generation of graphics cards, Nvidia had managed to tweak its architecture enough that you effectively got all of the benefits of a die-shrink, without having one. Imagine what it would've been like had Maxwell hit the 20nm lithography we expected. Imagine what Pascal is going to be like when it arrives next year.

A year down the line, the 980 is still a great card, especially since the release of the Fury and Fury X has encouraged its first real price drop. With this outstanding Palit card being almost £100 cheaper than the Fury – and a great deal less than the Fury X – it's a fantastic GPU for your 1440p gaming rig.

The GPU here is seriously overclocked, as the GTX 980 is generally capable of, and comes with a 0dB cooler that only really needs to kick in at peak gaming performance.

Right now though, 1440p is the limit of the 4GB frame buffer the GTX 980 sports. So 4K gaming is possible, but too much of a compromise for this card. It's a toss-up between this and the Fury, and in the end it's going to come down to finances and personal preference. The Fury is quicker and has superior memory tech, but the GTX 980 is cheaper and less power hungry.

SPECIFICATIONS

GPU	GM 204
CUDA cores	2,048
Memory capacity	4GB GDDR5

VERDICT 8

Palit GTX 980 Super JetStream

JET Still a great GPU; quality cooling; sterling 1440p perf.

WINGS Not a 4K gamer, with that 4GB VRAM.

£357, www.nigelohara.com

XFX Radeon R9 390X

Deserving of a new name?

IT'S REALLY EASY to get caught whining about feeling misled about this generation of AMD cards. The Fury cards and their Fiji GPUs are the only new graphics silicon AMD has really put the time into for this year's launch. Everything else is essentially a re-branded version of the last-gen option, with a few light tweaks here and there.

But those tweaks have made a real difference. While this Grenada XT GPU is little more than the Hawaii XT chip from the ol' R9 290X, AMD has squeezed a little more speed from its clocks – an extra 50MHz – and bundled in double the memory. Whether that's enough to mean the GPU deserves a new name is neither here nor there.

While the R9 390X is a lot quicker than the R9 290X it's replacing, it's also effectively the same price. Now, before we get ahead of ourselves, that 8GB frame buffer isn't going to suddenly deliver 4K gaming performance for this ageing architecture – there's almost no difference between the 290X and 390X at the highest resolution – but it does deliver performance improvements almost across the board at lower levels.

Almost... because we did experience some weird issues with this card and *GRID 2*. But for everything else, even the demanding *GTA V*, it delivered impressive performance figures. Most obviously in the minimum frame rates, especially with Rockstar's modern classic.

But its li'l brother, the straight R9 390, is the issue here. It's practically as good, with a notable saving too.

SPECIFICATIONS

GPU	Grenada XT
GCN cores	2,816
Memory capacity	8GB GDDR5

VERDICT 7

XFX Radeon R9 390X

GRENADA Hefty frame buffer; quality 1440p performance.

GRENADE Re-branded GPU; R9 390 is almost as good.

£310, www.ebuyer.com

Sapphire R9 390 Nitro

Hawaii Pro, with added nitrous

AMD ALWAYS SEEMS to pull off the same trick; release two cards based on very slightly different GPUs, with very slightly different performance numbers, and demand a lot more for one than the other.

Inevitably, we then look at the lower-spec card with almost the same gaming prowess and question why anyone would pick the pricier option. Such is the way with the Fury and Fury X. Such is the way with the 290 and 290X. And so it is with the 390 and 390X.

And when you throw into the mix that this new Sapphire Nitro branding means this overclocked card gets a Tri-X cooler attached to it, you know things aren't looking too good for the 390X. Couple all that with the fact the 390 also performs better than the top AMD GPU of the last generation and we have a great mid-ranger on our hands.

With most games you'll get excellent 1440p performance out of it, and for a pretty impressive price, too. That Sapphire cooler on this version means it maintains a chilled disposition even in the most aggressive of gaming arenas, and the 8GB frame buffer means it can take every high-res texture that *GTA V* or *Shadow of Mordor* cares to toss its way.

It may be another exercise in re-badging GPUs for AMD, but the little tweaks the team has made to this card's silicon have made it very much worth the effort. We may not be hugely impressed with the Fury, but the work it has done on the 390 almost makes up for it.

SPECIFICATIONS

GPU	Grenada Pro
GCN cores	2,560
Memory capacity	8GB GDDR5

VERDICT 9

Sapphire R9 390 Nitro

NITROUS Faster than the 290X; almost as quick as the 390X; enormo-buffer.

NOXIOUS Old architecture; drops frames to the 970.

£265, www.scan.co.uk

Gigabyte GTX 970 G1 Gaming

Ignore the shenanigans

THERE'S GENUINELY a lot to like about the GTX 970, despite all the grumbling surrounding its offset frame buffer. It's a good gamer and comes at a decent price, too.

The issue is that Nvidia didn't disclose the smart work it had done with the GPU and the VRAM. To ensure it kept more of the actual GPU logic, Nvidia's engineers did some clever stuff splitting the frame buffer. Had it not done so, the chip would have lost a lot more of the good stuff. Unfortunately, it didn't disclose this and we saw games using over 3.5GB of VRAM struggling on the GTX 970.

But then this isn't a GPU you'd use for seriously taxing 4K gaming, anyways. You can get up there in the VRAM stakes with gaming at 1440p – *GTA V* and *Mordor*'s texture packs do that – but elsewhere, the GTX 970 really fits the bill for a mid-range graphics card.

And Gigabyte's version comes with the excellent triple-fan Windforce cooler, which allows this card to be seriously overclocked without melting a hole in your motherboard. Even at its hottest, it doesn't top 64ºC.

Its biggest rival is that impressive R9 390. These two GPUs trade blows across most of our benchmarking suite, with AMD taking the lead in one test and Nvidia winning others. Where the 390 does win though is in the more modern games, which need over and above the 3.5GB / 4GB frame buffer this card is sporting, even at 1440p. That, and the fact the AMD card is cheaper, means we give the nod to the 390 here.

SPECIFICATIONS

GPU	GM 204
CUDA cores	1,664
Memory capacity	3.5 + 0.5GB GDDR5

VERDICT 8

Gigabyte GTX 970 G1 Gaming

G1 Cool 'n' quick; decent price.

M25 Pricier than the 390; suffers at top settings in modern games; frame buffer-gate.

£275, www.ebuyer.com

Asus GTX 960 STRIX

2GB just ain't enough any more

THE GTX 960 IS PRETTY MUCH the bottom of the ladder when it comes to the modern Maxwell lineup – until the GTX 950 arrives to replace the ol' GTX 750 GPUs, anyways. And what that means is we're talking about a resolutely 1080p gamer's card.

You can, of course, run a 4K monitor from this GPU, but even at 1440p settings, you'll struggle to play the latest games at top settings with any semblance of buttery smooth gaming. Throw this Asus STRIX card at anything running on a 1080p screen, though, and that's exactly what you'll get. *BF4* runs like a dream at top settings and you can get great performance out of *GTA V*, too. *Shadow of Mordor*'s texture pack, though, is still seriously demanding, even at 1080p, so we only saw 36fps on average, which is still just about acceptable.

The big issue with this card is that 2GB frame buffer. Where once that was plenty, in this brave new resolution-heavy world of ours, it's simply not enough for the most demanding of games and is likely to leave you wanting when new titles drop in the big autumn gamegasm.

But when it's coated in Asus's STRIX armour, it's still a tempting sub-£200 GPU. The 0dB cooler only spins up when you get up to gaming speeds and even then this card stays seriously cool and quiet. At this end of the market though, AMD has got it sewn up again. The competing R9 380 is similarly priced and rocks that 4GB frame buffer to give it some much-needed longevity.

SPECIFICATIONS

GPU	GM 206
CUDA cores	1,024
Memory capacity	2GB GDDR5

VERDICT 7

Asus GTX 960 STRIX

STRIX Low-powered; decent at 1080p.

STRUCK OUT Weedy frame buffer; fails at 1440p top settings; the 380 takes it.

£169, www.scan.co.uk

MSI R9 380 Gaming 4G

Something old, something new

WE'VE GIVEN AMD a little bit of strife for the whole rebranding thing with this current generation of GPUs. And it does feel a little like the company is treading water until either TSMC or Global Foundaries get their 16nm acts together and provide it with a production process for the future. Which is all to say the R9 380 is another old-school GPU; though this is actually the second-most modern after the Fiji chips.

The Antigua GPU at the heart of the R9 380 is essentially the Tonga silicon from the previous generation. That means it's got the latest class of GCN architecture, rocking the same 256-bit memory bus as the R9 285 because of the lossless colour-compression tech boosting its memory performance.

That's some modern AMD goodness that's missing from the higher-end 390 cards. The real big win for this card is – and we know we keep harping on about it – the chunky memory buffer. With 4GB on this relatively low-end GPU, you're getting a quality 1080p gaming card that's more than capable of mixing it with the most graphically demanding games of now and tomorrow.

The 2GB buffer of the GTX 960 is what's holding it back, but with double that capacity, the R9 380 is a far more capable gamer, even offering very playable performance at 1440p too. Where you do need to be careful though is with the 2GB versions of the R9 380 that are floating around. Those are definitely to be avoided.

SPECIFICATIONS

GPU	Antigua
GCN cores	1,792
Memory capacity	4GB GDDR5

VERDICT 8

MSI R9 380 Gaming 4G

GAMING Beefy buffer; decent at 1080p; great MSI cooler.

GAMMY Avoid the 2GB; 4GB is pricey.

£179, www.dabs.com

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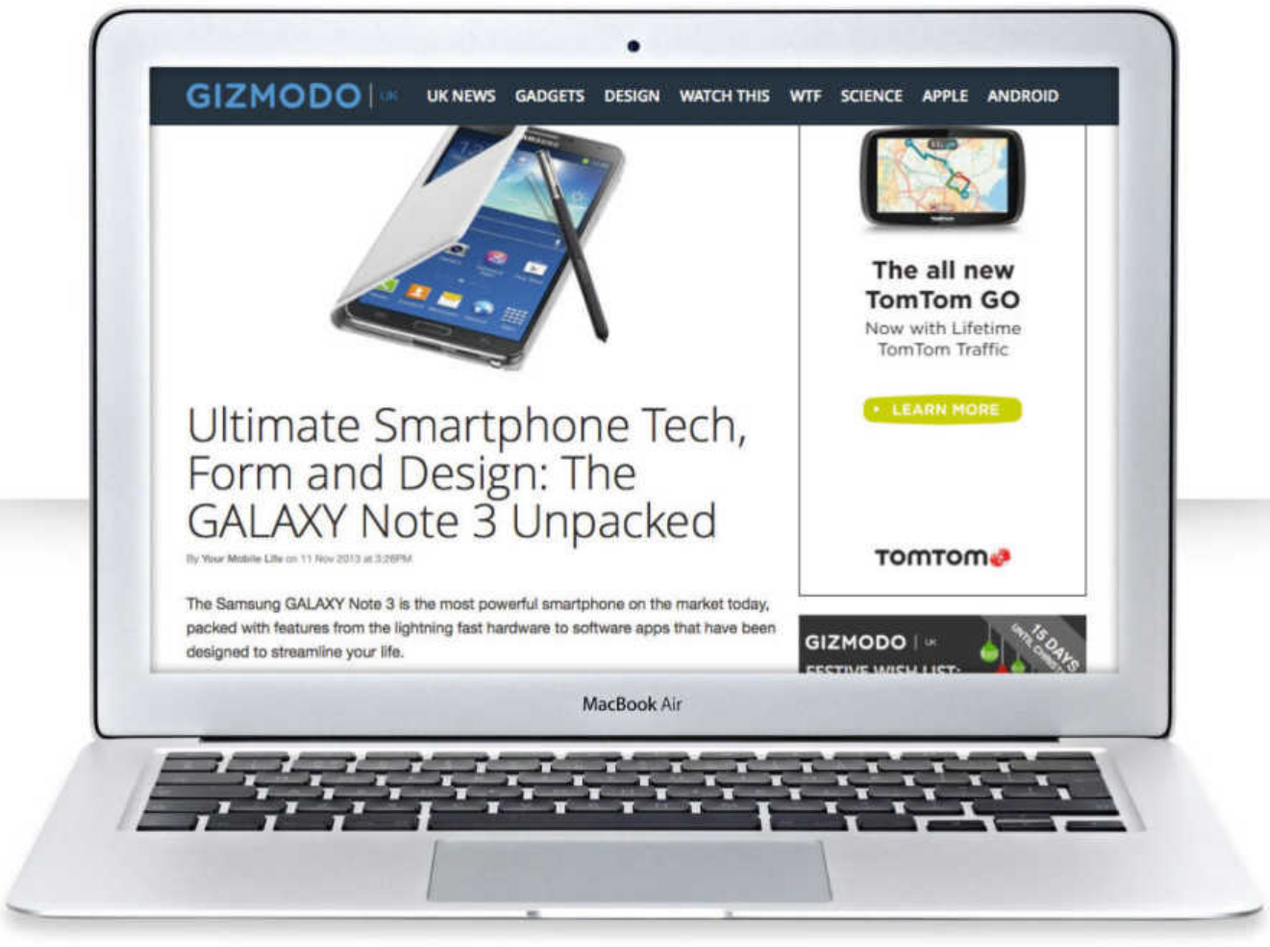

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HOW WE TESTED

Our test rig comprises an Intel Core i7-5960X in an Asus X99-Deluxe motherboard with 16GB of 2,133MHz DDR4 memory under Windows 8.1. All of the graphics cards are tested with the latest release drivers on the same benchmark settings to ensure a fair test. We've included the minimum frame rate results as well as the overall average to indicate how smooth an experience you're getting from each graphics card.

SPECIFICATIONS

	Website	Price	GPU	Cores	Memory capacity	Memory bus	TDP	Peak temperature °C	Score
Nvidia GTX Titan X	www.nvidia.com	£830	GM 200	3,072	12GB GDDR5	384-bit	250W	83	7
Inno3D iChill GTX 980 Ti Black	www.inno3d.com	£630	GM 200	2,816	6GB GDDR5	384-bit	250W	68	9
AMD R9 Fury X	www.amd.com	£510	Fiji XT	4,096	4GB HBM	4,096-bit	275W	64	7
Sapphire R9 Fury Tri-X	www.sapphiretech.com	£444	Fiji Pro	3,584	4GB HBM	4,096-bit	275W	79	8
Palit GTX 980 Super JetStream	www.palit.biz	£357	GM 204	2,048	4GB GDDR5	256-bit	165W	75	8
XFX R9 390X	www.xfxforce.com	£310	Grenada XT	2,816	8GB GDDR5	512-bit	275W	80	7
Sapphire R9 390 Nitro	www.sapphiretech.com	£269	Grenada Pro	2,560	8GB GDDR5	512-bit	275W	71	9
Gigabyte GTX 970 G1 Gaming	www.gigabyte.com	£275	GM 204	1,664	3.5 + 0.5GB GDDR5	256-bit	145W	64	8
Asus GTX 960 STRIX	www.asus.com	£169	GM 206	1,024	2GB GDDR5	128-bit	120W	64	7
MSI R9 380 Gaming 4G	www.msi.com	£179	Antigua	1,792	4GB GDDR5	256-bit	190W	78	8

1920 X 1080 BENCHMARKS (1080p)

	Battlefield 4	Total War: Attila	GRID 2	GTA V	Shadow of Mordor
Nvidia GTX Titan X	64 / 122	21 / 43	**132 / 180**	12 / 103	49 / 108
Inno3D iChill GTX 980 Ti Black	**87 / 134**	**36 / 45**	121 / 177	**8 / 115**	**48 / 123**
AMD R9 Fury X	60 / 100	29 / 39	114 / 146	10 / 88	47 / 98
Sapphire R9 Fury Tri-X	61 / 97	28 / 37	100 / 134	31 / 85	29 / 93
Palit GTX 980 Super JetStream	62 / 113	23 / 36	129 / 162	21 / 87	42 / 89
XFX R9 390X	48 / 90	18 / 31	62 / 77	21 / 78	40 / 83
Sapphire R9 390 Nitro	47 / 82	21 / 30	91 / 118	20 / 74	38 / 79
Gigabyte GTX 970 G1 Gaming	47 / 90	21 / 30	104 / 131	21 / 75	50 / 74
Asus GTX 960 STRIX	31 / 55	9 / 18	71 / 88	9 / 49	17 / 36
MSI R9 380 Gaming 4G	34 / 53	11 / 18	73 / 87	12 / 48	18 / 45

2560 X 1600 BENCHMARKS (1600p)

	Heaven	Battlefield 4	Total War: Attila	GRID 2	GTA V	Shadow of Mordor
Nvidia GTX Titan X	19.8 / 60.4	46 / 83	19 / 28	105 / 138	**7 / 70**	48 / 74
Inno3D iChill GTX 980 Ti Black	**19.6 / 70.7**	**64 / 99**	**20 / 32**	**118 / 157**	**7 / 70**	**50 / 85**
AMD R9 Fury X	19.4 / 49.9	36 / 73	18 / 27	90 / 111	10 / 62	35 / 71
Sapphire R9 Fury Tri-X	19.8 / 46.9	40 / 69	18 / 25	82 / 105	16 / 61	32 / 67
Palit GTX 980 Super JetStream	18.2 / 48.6	42 / 73	13 / 23	93 / 118	16 / 57	36 / 61
XFX R9 390X	16.7 / 38.8	35 / 61	14 / 21	62 / 77	17 / 55	29 / 58
Sapphire R9 390 Nitro	15.9 / 37.8	34 / 58	13 / 20	70 / 88	15 / 52	28 / 56
Gigabyte GTX 970 G1 Gaming	15.4 / 38.4	34 / 57	13 / 19	76 / 96	19 / 49	38 / 51
Asus GTX 960 STRIX	10.5 / 23.1	23 / 37	6 / 11	48 / 59	6 / 31	14 / 24
MSI R9 380 Gaming 4G	11 / 23.6	25 / 39	7 / 12	46 / 57	11 / 34	10 / 35

3840 X 2160 BENCHMARKS (4K)

	Heaven	Battlefield 4	Total War: Attila	GRID 2	GTA V	Shadow of Mordor
Nvidia GTX Titan X	17.5 / 26.5	25 / 43	6 / 14	59 / 78	11 / 36	29 / 38
Inno3D iChill GTX 980 Ti Black	**13.3 / 29.3**	**30 / 49**	**9 / 17**	**71 / 91**	**9 / 41**	**35 / 46**
AMD R9 Fury X	11.6 / 22.7	21 / 40	3 / 12	57 / 70	3 / 35	18 / 38
Sapphire R9 Fury Tri-X	10.8 / 21.3	23 / 38	7 / 12	50 / 66	1 / 33	14 / 36
Palit GTX 980 Super JetStream	10.3 / 20.6	23 / 38	6 / 11	46 / 67	6 / 23	26 / 33
XFX R9 390X	9.5 / 17.3	19 / 31	6 / 10	44 / 55	12 / 28	22 / 31
Sapphire R9 390 Nitro	9.3 / 16.4	17 / 30	6 / 10	41 / 52	12 / 26	17 / 31
Gigabyte GTX 970 G1 Gaming	9.2 / 16.2	17 / 29	4 / 9	39 / 54	12 / 24	19 / 27
Asus GTX 960 STRIX	5.8 / 9.6	6 / 12	1 / 4	27 / 35	2 / 8	6 / 12
MSI R9 380 Gaming 4G	7 / 11.1	10 / 19	1 / 6	29 / 36	4 / 11	8 / 20

Best scores are bolded. Overall winner is highlighted. Game results are all minimum/average fps.

And the winner is...

Inno3D iChill GTX 980 Ti Black

WE'RE AT A WEIRD MOMENT in the history of graphics cards. On the one hand, it's a fantastic time to go out and buy a new GPU because there's simply never been this amount of GPU processing power available at any price.

On the other hand, though, you've got a vast number of cards still rocking ageing graphics architectures with potentially hugely updated versions on the way. That means, of the myriad cards we've got in our test here, only a few of them could genuinely be recommended for purchase right now.

The top-end of the market is the toughest – mostly because, and we can probably all agree on this, pricing has become utterly insane. At the top of the pile is Nvidia's GTX Titan X, at £800. Mental. And now it's not even the fastest card, only holding its 12GB frame buffer over the rest of the graphics market.

Then we've got AMD's only genuinely new GPUs of this latest, late generation. The two Radeon Fury cards simply don't do anything to make them worthwhile. They are cheaper than the top Nvidia cards, but lose out in the performance stakes despite having that brand new memory technology. They only have 4GB each, and that's simply too little to expect to hit high-res gaming speeds in the future of gaming.

ALL-ROUND CHAMPION

Up top then – and probably overall – the GTX 980 Ti is the only high-performance card worth spending money on right now. The 6GB frame buffer and exceptional gaming performance will mean that, even when the 16nm GPU revolution happens later this year, it will still be able to hold its head up high in the performance stakes.

Nvidia's old GTX 980 could still be worth a punt if you can find it for closer to £300 – again, it's not going to cope well with the 4K future with its older GPU and 4GB frame buffer, but it's an absolute rock at 1440p. This Palit version is super-quiet and super-cool.

Surprisingly, the re-branded Hawaii cards, specifically the excellent R9 390, have made themselves more worthy than we initially expected. The 390X is impressive for the fact it outperforms its 290X forebear. But then so does the straight 390, and for considerably less cash.

And that 8GB memory capacity means the 390 is going to still be gaming happily at 1440p for a good while to come, even when the Arctic Islands and Pascal GPUs arrive sometime in 2016. This Sapphire R9 390 Nitro is the other bright spot in our supertest, and is the one we'd recommend for a mid-range card.

Down at the bottom of the pile, the much-maligned GTX 970 still has some skills, but with the performance of the 390 and its hefty frame buffer, the GTX 970 is not going to be able to stand out against the AMD card.

And propping things up at the real budget end, where the GTX 960 goes head-to-head with the R9 380, we've again got to hand the glory to the Radeon offering. And yet again, that's down to the additional frame buffer. The 4GB capacity of the R9 380 isn't going to mean you can suddenly nail super-high resolutions, but it does mean that at a more standard resolution, it's going to cope with even the most demanding of future titles. ■

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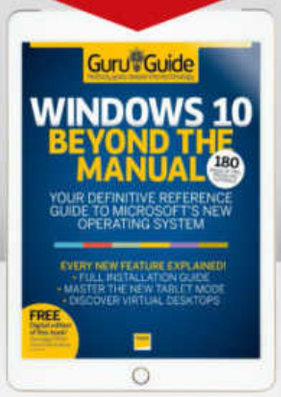

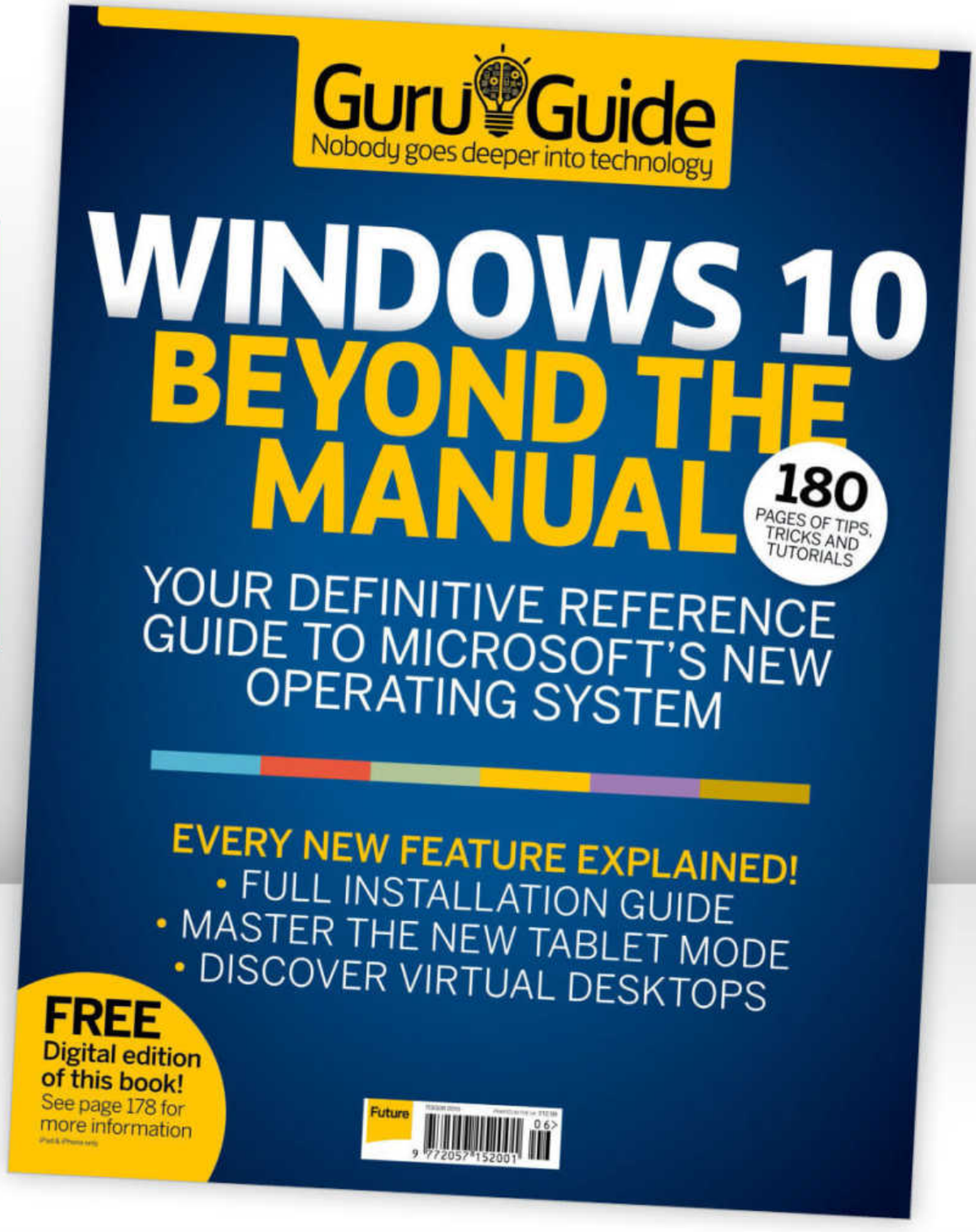

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The High-Bandwidth Bomb

The PC platform, and motherboards in particular, are about to drop a bomb on your desktop

IN THE FUTURE, motherboards will be all about bandwidth. Actually, they already are. That's because the big news for the PC platform is a whole bunch of new interconnects. And they're all about boosting bandwidth. They're also borderline baffling. Firstly, there's the bonkers nomenclature. Whoever thought 'SFF-8639' was a goer needs to be strung up with SATA cables. More on that later. The confusing naming, that is, not death by middling-bandwith cable connects.

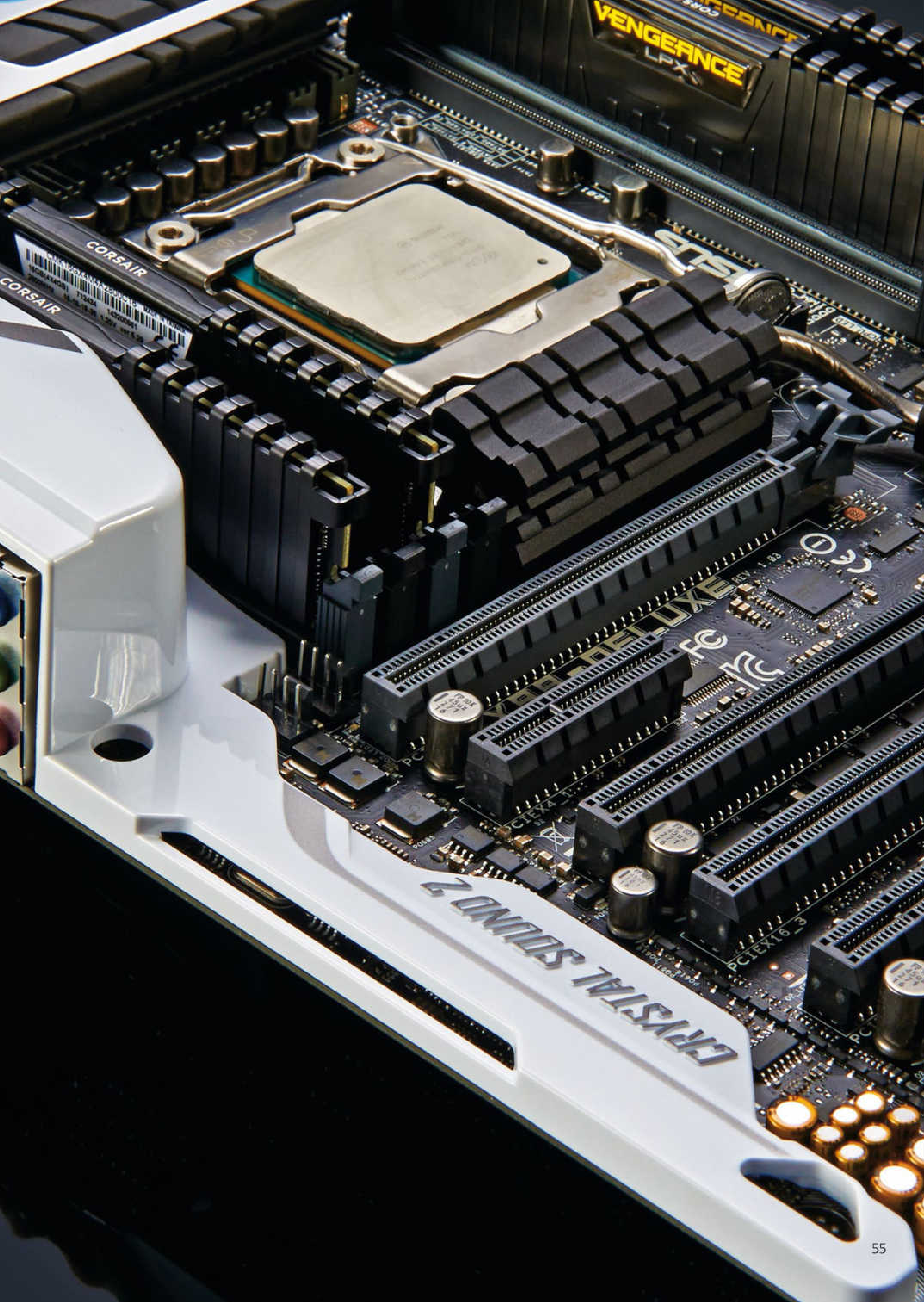
Then there's the fusing of multiple standards into one, plus the replacement of others with multiple options. Nightmare.

Maybe it was always this way. Perhaps our spectacles are growing ever more rose-tinted. Until recently, it was just PCI Express for graphics, SATA for hard drives and USB for everything else. Wasn't it?

Okay, we had to keep up with little upgrades, but now? Now there's M.2, which is a sort of PCI Express for SSDs, not forgetting that it'll need to be of the NVMe variety to really deliver next-gen performance. AHCI won't cut it. Unless it's SATA Express, which is a bit like a fusion of PCI Express and SATA. Except nobody is using it and it looks like SFF-8639 will be the thing, until they re-named it U.2.

Meanwhile, USB 3.1 has been tweaked into USB 3.1 and USB Type C at the same time as assimilating Thunderbolt, which may not live on as a standalone, er, standard. Yup, it's a right old mess.

Right here, then, we have an all-encompassing guide to these new standards – what they all mean, how they work, whether you'll want 'em, the works. Then we'll round up the latest mobos and sniff around the actual implementation of these new standards, even though not all are fully available and, in some cases, compatible devices barely exist. Confused enough? Let's get cracking.


VENGEANCE
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CRYSTAL SOUND 2

A bit like the One Ring, USB Type C has a bit of a problem with megalomania. It wants to own other interfaces, too.

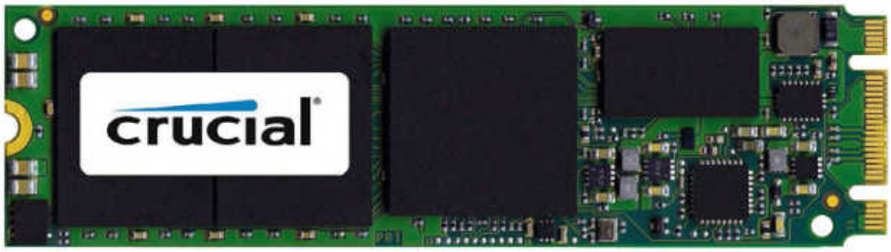
Let's start with USB. It's the mother of all modern interconnects.

To say USB has been a huge success is a something of an understatement. USB has become the very definition, the Platonic form found hanging in the intergalatic ether, of utter, crushing ubiquity.

What began in 1997 as something to make it easier to plug stuff into PCs has ballooned into the default wired interface for almost anything digital. Charging, connecting, communicating. If it's done over a wire, it's probably USB.

USB has also historically majored in maximum backwards compatibility, both in terms of the physical format and the digital signalling. It's been revised several times in the name of boosting bandwith from the original 1.0 spec to today's 3.0. That's involved a journey from 12Mbps at launch through 480Mbps for USB 2.0, 5Gbps for 3.0 and latterly 10Gbps for USB 3.1.

What hasn't changed is the familiar rectangular socket. Throughout the bandwidth bump cycles, that has remained.



Above: Initially optimal for portible PCs, M.2 is now a common desktop storage interface.
Top of page: Type C USB connectors will be compatible with Thunderbolt.
Below: Since 1997, USB has grown into an ubiquitous interface.

Indeed, older devices could plug into revised sockets and function fine, though obviously the lowest common denominator prevails – device or host will default to the slower of the two.

Of course, USB has acquired a few frills over the years. Mini and micro sockets for smaller portable devices have appeared, and the standard rectangle 'A' connector has also been accompanied by the squarer 'B' interface, the latter being familiar as the interface used most commonly to hook up multi-port USB hubs.

When USB 3.0 appeared, the standard got its first electrical upgrade, too. The pins and wires went from four plus a shield, to nine plus shield. The plastic internals of the female sockets were also coloured blue to help aid identification. But the new physical interface was cleverly designed, so backwards compatibility was retained.

With the introduction of USB Type C, however, the near 20-year run of backwards compatibility will be broken. But for some pretty decent reasons. First up is ye olde bandwidth. Developed at around the same time as USB 3.1, Type C supports all 10Gbps of USB 3.1. Yay.

The other raison d'être is simplicity. Like Apple's Lightning and also the Thunderbolt interface, it's reversible. In other words, you can whack it in without worrying whether you've got it the right way up. That sounds like a minor convenience. But if you're fumbling around behind a PC in the dark, for instance, it's a fairly significant boon to be able to just ram it in.

LORD OF THE INTERFACES

Even better, Type C is good for both devices and hosts, putting an end to the Type A and Type B dichotomy. It's also titchy in terms of its physical proportions. Much, much smaller than the ubiquitous Type A rectangle. So, it's as good for desktop kit as it is mobile clobber. Think of it as the One Ring of USB. It'll rule them all.

Actually, a bit like the One Ring, USB Type C has a bit of a problem with megalomania. It wants to rule more than just USB. It wants to own other interfaces, too. Perhaps that's not terribly fair. What's actually happened is that Intel's third revision of its Thunderbolt interface includes a USB 3.1 controller and is compatible with the Type C connector.

That's an intriguing proposition because it means you can have all the benefits of USB and Thunderbolt in one interface. From USB, you get the broad compatibility and some decent speed. From Thunderbolt, you get some seriously sexy new goodies.

The first is DisplayPort support. That means you can hook up all kinds of cutting-edge monitors and displays to what is a general-purpose interface. Then there's PCI Express support, which is handy for external drives, but also opens up options for running external graphics cards.

Thunderbolt 3 also ups its bandwidth ante to fully 40Gbps. Consider if you will DisplayPort, USB 3 and PCI Express over a single Thunderbolt port. Nice. Beyond Apple's MacBooks, Thunderbolt hasn't gained much traction to date. But aligning it with USB Type C will almost certainly change that.

Of course, much of this technology hasn't reached existing motherboards or PCs generally. But there have been plenty of changes when it comes to storage interconnects. Very soon after the introduction of the first solid-state drives, it became clear the SATA standard wasn't going to be good enough.

At first, it was a simple bandwidth issue. In practice, the fastest SATA 6Gbps iteration tops out at around 550MB/s. Nice compared to magnetic drives of yesteryear. But pedestrian in an age of solid-state componentry and GB/s of system and graphics memory bandwidth.

More recently, it's become clear that the AHCI protocol that PCs use to control hard drives is suboptimal for SSDs. The solution, as it turns out, is PCI Express. Unfortunately, the solution is also more complicated than that. Initially, it seemed like a new standard that combined SATA physical interconnect with the modular bandwidth of PCI Express was the future for desktops and 2.5-inch drives. This is, or perhaps was, SATA Express.

In parallel, another new standard was born. It's known as M.2 and involves compact drives based on bare circuit boards, plugging directly into slots rather than via cables. M.2 is also based on PCI Express and looked ideal for portable PCs and micro systems.

At the same time, a new control protocol optimised for solid-state storage, NVMe, popped up and the future of PC storage seemed to make sense. And then it didn't. Firstly, while SATA Express was widely adopted by motherboard makers, actual drives failed to materialise.

COMPETING FOR LANES

Meanwhile, although M.2 drives were launched and motherboards had slots to accept them, those drives lacked NVMe support, so the true promise of PCI Express storage wasn't realised. What's more, as we got to grips with the core concept of PCI Express storage, it became obvious that current Intel platforms aren't really built with it in mind.

That's because the native PCI Express connectivity is built into the CPU itself. For Core i5 and Core i7 CPUs on the LGA1150 socket, that connectivity is limited to a single port of single lanes. In an ideal world, all 16 of those lanes will be dedicated to graphics. Take just one away for use with an SSD and the graphics subsystem will drop down to eight lanes.

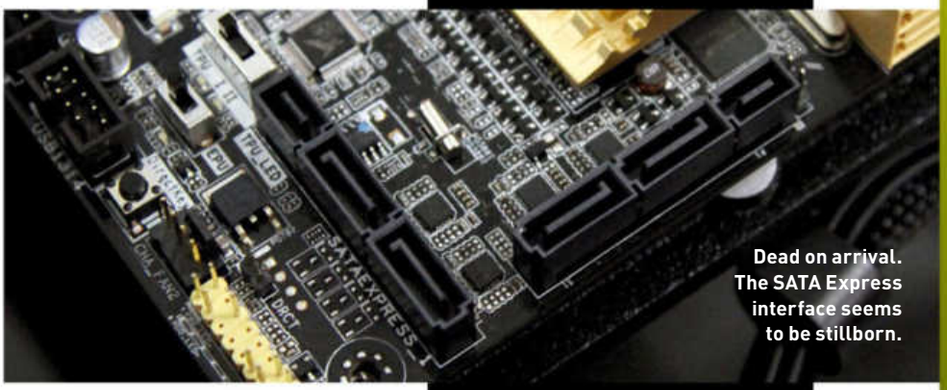
The first USB Type C flash drives are just starting to appear on the market.

The latest USB 3.1 standard ups the ante to an impressive 10Gbps.

Of course, what's left of the external chipset, the PCH, does provide another eight lanes. But these are slower 2.0-spec lanes rather than the CPU's 3.0 lanes. More to the point, the PCH connects to the CPU via a DMI 2.0 bus that shares its 20Gbps across all subsystems. So, any PCI Express drives could be battling with the likes of USB devices for bandwidth.

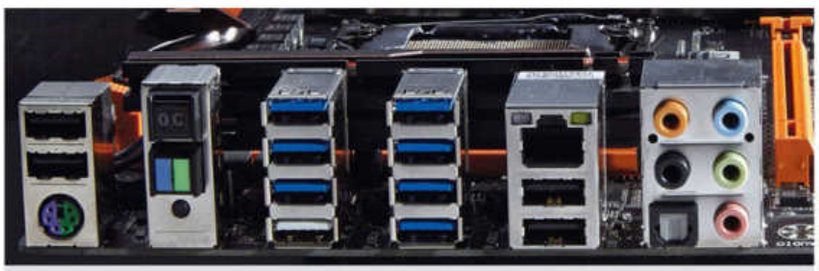
In an ideal world, the CPU itself would have a few spare lanes to hook up to SSDs. That's exactly what will happen with Intel's next-gen Skylake CPUs. They get 20 native PCIe lanes and thus four to use for storage. The final part of the PCIe storage puzzle is U.2. For more on that, point your peepers at "U.2 comes to the PC", to the right.

Put all that together and the PCs of the future begin to take shape. Imagine, perhaps, a PC where all peripherals, including your ultra hi-res monitor, are daisy-chained off a single port. Meanwhile, you'll have storage that cranks out the sort of GB/s speeds we used to associate with RAM. We may not be there yet, but at least you now know what's coming.



Dead on arrival. The SATA Express interface seems to be stillborn.

Most modern motherboards have a silly number of USB Type A ports.



HIGH-BANDWIDTH INTERCONNECTS IN FULL

Interconnect	Usage	Physical interface	Maximum bandwidth
SATA	**Storage, 2.5-inch and 3.5-inch hard drives and SSDs**	**Cable**	**600MB/s**
SATA Express (probably dead)	**Storage, 2.5-inch SSDs**	**Cable**	**2GB/s**
U.2 (formerly SFF-8639)	**Storage, 2.5-inch SSDs**	**Cable**	**4GB/s**
M.2	**Storage, solid-state drive boards**	**Slot**	**4GB/s**
USB 3.1	**Almost anything bar 4K-plus displays**	**Existing Type A and B connectors**	**1.25GB/s**
USB Type C	**Almost anything bar 4K-plus displays**	**New compact, universal and reversible connector**	**1.25GB/s**
Thunderbolt 3	**Almost anything including 4K-plus dislays**	**Physically compatible with USB Type C**	**5GB/s**

U.2 comes to the PC

NO, the rock band everyone loves to hate hasn't started shilling for Intel instead of Apple. Instead, if there is a musical connection, it's the artist formerly known as Prince. For U.2 is the storage interconnect formerly known as SFF-8639.

Yes, really, SFF-8639. We would ask who on Earth makes this crap up and expects consumers to have a clue what it means. But SFF-8639 was originally intended as an interconnect for enterprise-class systems, meaning that friendly branding our pretty little heads can cope with understandably wasn't a top priority.

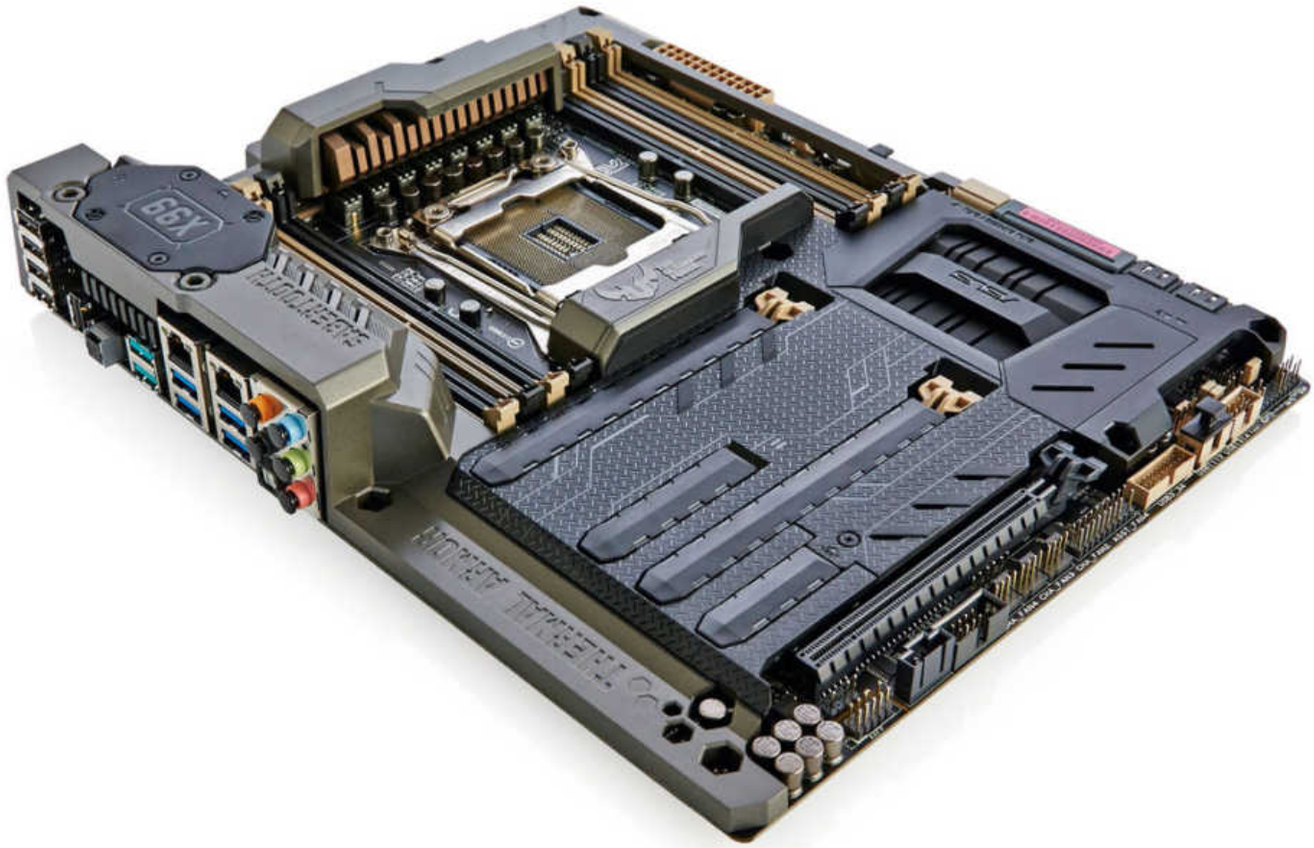
However, SATA Express hasn't taken off, and with SFF-8639 gaining some traction generally, Intel and the SSD Form Factor Working Group has decided to rebrand it 'U.2' to make it easier to grasp and also align it with the existing M.2 interconnect nomenclature.

U.2 is similar to SATA Express in that it's a cable-connected interface similar to SATA, except it's using the PCI Express protocol. That means it's suitable for use with the 2.5-inch form-factor SSDs that were the default option, until M.2 boards came along.

The difference is that U.2 supports up to four PCIe lanes to SATA Express's two lanes. Thus, U.2 maxes out at 4GB/s, rather than 2GB/s.

Whether U.2 will truly take off, however, is unknown. One factor that may prevent wide adoption is, would you believe, cabling cost. Apparently, U.2 requires cabling with multiple individually shielded cables, driving up cable costs. Not attractive for motherboard makers operating under monstrously tight margins.

Whatever happens, however, we just hope it happens soon. That way we can all relax and stop swotting up on high bandwidth interconnects as if every week is summer term in secondary school.



ASUS X99 TUF SABERTOOTH

So sleek, so stealthy, so good

ASUS IS WELL KNOWN for its high-end componentry. Yes, it can come at a premium, but it's often money well spent if you're looking for feature-rich, reliable products. So, does TUF's latest X99 Sabertooth board hit that mark? Oh yes.

Since launch Asus's TUF brand has focused on two things: reliability and consistency. And, although the RoG and Workstation series still exhibit these traits, it's hard to argue with TUF's reputation for being the workhorse of the breed. Certainly, over the three years since its first Z77 chipset and its first thermally armoured boards, these have been values that Asus has aggressively expanded upon.

This board looks spectacular, hiding the vast majority of the all-black PCB under the thermal armour. This gives the Sabertooth an incredibly clean look. Whether or not you believe in the heat-regulating effects of TUF's layers of reinforced steel and plastic, it's hard to deny it looks stunning.

Internally, the board supports tri-SLI and Crossfire, thanks to three PCIe 3.0 lanes (for 16x16x8 or 16x8x4, depending on which monster you plug in to that 2011 socket). This gives you enough graphical horsepower to not bat an eyelid when staring down the barrel at our eternal enemy – frame rate. For storage, there's support for M.2 PCIe. Additionally, there's access to one SATA Express connection alongside eight standard SATA 6Gbps ports. What's insane is the fact Asus has managed to cram 11 fan headers across this board. But then that's something we've come to expect from Asus. With offerings such as Fan Xpert II and the TUF ICe chip solution (allowing for an additional 5 PWM controlled fans), the X99 outstrips almost all of the competition for cooling capacity.

For rear I/O, there's four USB 2.0 ports, four USB 3.0 ports and two of ASMedia's new 3.1 ports, allowing for transfer rates of up to 10Gbps. Unfortunately, there's no mention of USB 3.1 Type C, something that would've been nice on such a high-end board. Audio is handled with the standard 5.1 setup we've come to expect, with additional optical output, which is separated from the rest of the mobo. It's supported by TUF's audio tinkering to make sure there's as little electromagnetic interference as possible.

PLENTY OF BITE

Core features include Asus's current iteration of AI Suite and UEFI BIOS, all repackaged in TUF's military design, with easy automated overclocking features for the more faint-hearted.

As for performance, we overclocked our 5820K to a respectable 4.4GHz at 1.3v with relative ease, and achieved some strong benchmarks. The Sabertooth also comes with access to TUF Detective, a specialised USB port in the rear I/O, allowing you to hook up an Android device to monitor your mobo in real time, similar to the RoG Extreme Front Base, but with added utility and without being so cumbersome.

This Sabertooth is impressive. Its cooling potential is second to none, and certified with a five-year warranty, it certainly pulls its weight. Aesthetically, it's a beauty and we can't wait to get it into a proper build. We'll admit that it isn't cheap, but then if you're buying into the extreme edition processors, you're going to be used to paying that premium for reliability (and potentially looks, if you're into that kind of thing). If you're after a board that's a dab hand at gaming and overclocking, plus a dependable workstation, the Sabertooth is definitely worth your time.

VERDICT **9**

Asus X99 TUF Sabertooth

STALLION Feature-rich; thermal armour; sleek and sexy aesthetics; TUF Detective; huge cooling capacity.

MULE Expensive; additional fan can be noisy; no USB 3.1 Type C.

£286, www.overclockers.co.uk

SPECIFICATIONS

CPU support	Intel X99 / 2011
Form factor	ATX
USB 3.1 support	2x USB 3.1 Type A
M.2 support	M.2 PCIe SSD

ASROCK X99 E-ITX

Impressive engineering that struggles to find a home

INSANITY, thy name is ASRock. We don't think there's been many companies out there who have thought to themselves: "You know what we need to do? A 2011 socket, ITX form-factor, go!"

The ASRock X99 E-ITX is nothing short of an engineering miracle, fitting an extreme edition processor into the ITX form factor represents a huge challenge. Considering the socket alone takes up a quarter of the entire PCB, ASRock has been left with little-to-no room to manoeuvre. So, has it delivered on the promise of an insanity-packed Mini-ITX powerhouse? Sort of...

The board follows the traditional blue design SKU of the latest ASRock boards. Granted, you won't see much of it once you've slammed in a graphics card and two sticks of DDR4, but for what's it worth, it's not a bad-looking motherboard, at first... After you realise that you're left with that awkward-looking small form-factor custom CPU leaf blower, or a Cooler Master Seidon 120MM all-in-one, you might be feeling a little differently on the subject.

Internally, for storage you have access to one Ultra M.2 PCIe, four SATA 6Gbps ports and a single SATA Express port, for the lucky few who have access to something that runs that. There is, of course, the standard USB 3.0 connector awkwardly positioned behind the PCIe slot. For cooling capacity, it's the usual slim pickings you tend to find with ITX (though more than its Z97 little brother), with one CPU fan header and two chassis fan headers.

The rear I/O features four USB 3.0 ports, two USB 2.0 ports, an eSATA connector, the usual 5.1 audio connectors plus TOSLink, PS2 Combo port, two Gigabit Ethernet connectors and last, but certainly not least, the two USB 3.1 Type A connectors for up to 10Gbps transfer speeds with the latest storage devices.

As far as performance goes, it's as solid as the rest of them. Something ASRock boards are well known for is their potential to overclock, and this board is no exception. We achieved a stable 4.4GHz on our Core i7-5820K, and, as you can see from the benchmarks later in the feature, it pushed out some impressive numbers, even giving the Sabertooth a run for its money.

SO NOT COOL

Unfortunately, this board has one major setback, and that stems from the design of the socket itself. Although it's still reinforced with its own backplate, much like the other 2011 boards in the market, the mounting points don't correspond to the traditional 2011 form.

This means you're incredibly limited as to what coolers you can effectively use. You're stuck with either ASRock's included CPU heatsink (that although effective, sounds like a small hurricane, even on silent mode) or a Cooler Master Seidon 120mm or 240mm all-in-one liquid cooler with the included bracket. It's less than appetising for water-cooling enthusiasts and other PC builders.

There's no doubt the X99 E-ITX is an impressive piece of engineering from ASRock. If you're looking to set up an insane home server build with a 2011 chip at its heart, this could be a solid candidate.

Otherwise, however, the placement of this board in the market is a tad confusing. It doesn't really have the memory capacity or storage connectivity needed for a professional-grade workstation, nor is it entirely comparable to what you'd expect from high-grade gaming motherboards (because let's face it, if you're buying a 2011 socket to game on, you'll probably be investing in more than one GPU anyway).

VERDICT **7**

ASRock X99 E-ITX

POWERHOUSE Small form factor; impressive design; strong integrated cooling.

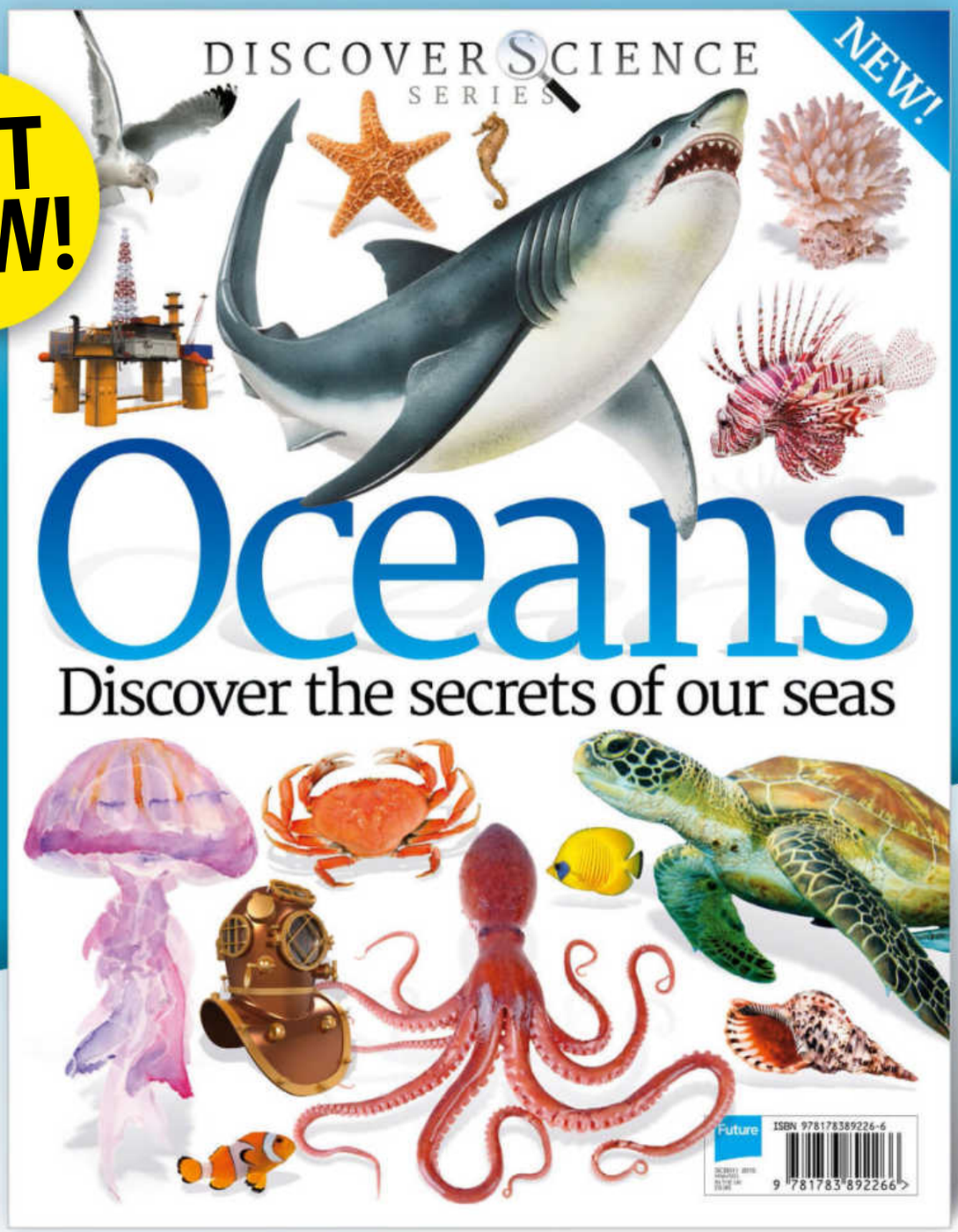
LEAKY ROOF Limited choice of coolers; no place in the market; not good looking.

£240, www.lambda-tek.com

SPECIFICATIONS

CPU support	Intel X99 / 2011
Form factor	E-ITX
USB 3.1 support	2x USB 3.1 Type A
M.2 support	Ultra M.2 PCIe SSD

DELVE DEEPER INTO NATURE



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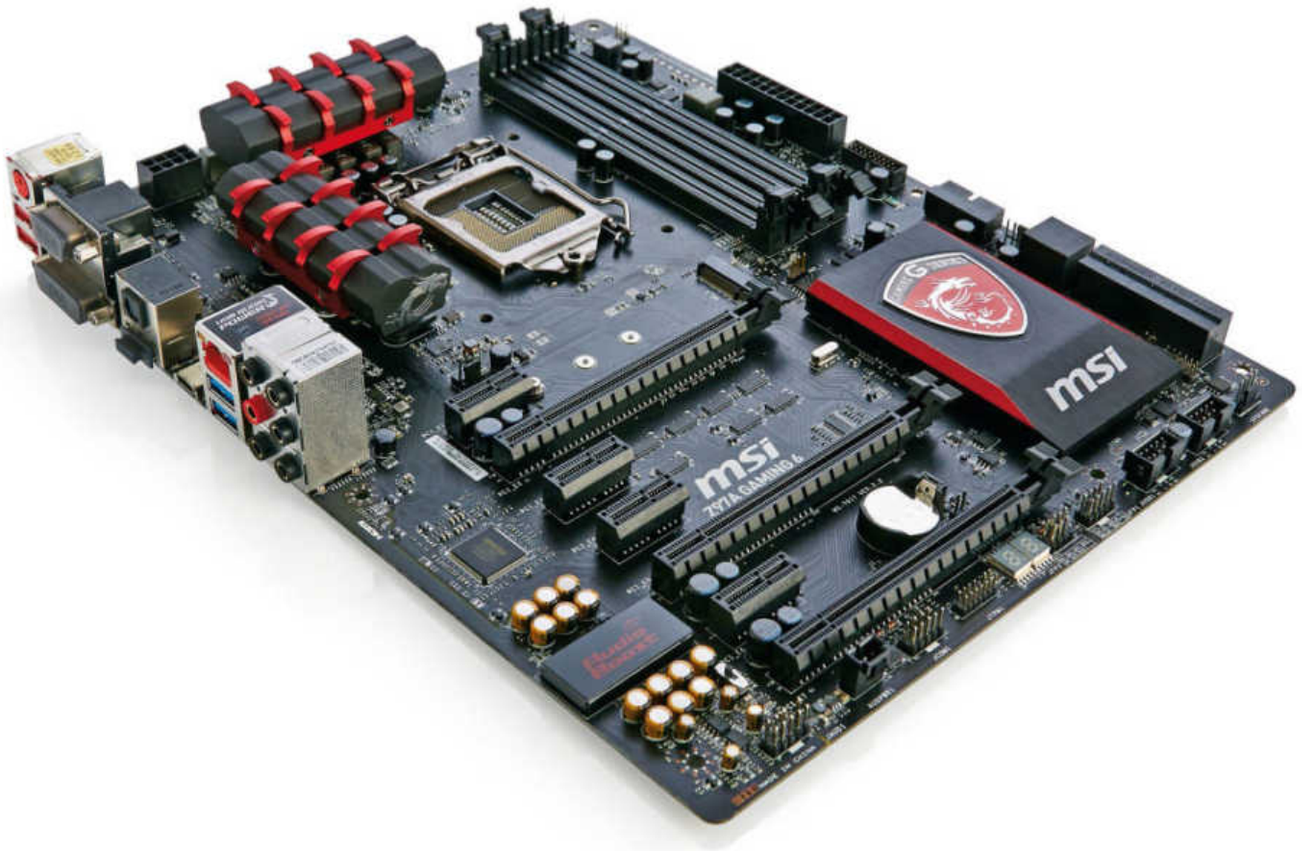


MSI Z97 GAMING 6

Great entry-level gaming motherboard

MSI GAMING, albeit a new line in MSI's arsenal of products, has had a tangible effect on the marketplace. And you can tell. With so many manufacturers creating their own 'gaming' lines in response to MSI's fiery dragon, it has quite the reputation to live up to. Is MSI's Z97 Gaming 6 motherboard worthy of wearing the prestigious red garb in line with so many of its brothers?

The board comes in at a lower price point in comparison to the alternatives in this supertest, even for this socket. As such, you tend to lose a lot of the flair you get from other higher-priced alternatives.

This means smaller heatsinks, less glamorous cooling solutions and generally not a lot of colour beyond that. Despite that, however, it still features a fully black PCB, black and red Northbridge heatsinks and a rather nice illuminated line that separates the audio solution from the rest of the PCB, just in case we didn't know that it wasn't separated already. But we have to admit, we like the implementation of it.

Let's face it, however, this is only half of the story. What about the guts of it? Well, the Gaming 6 comes with an internal M.2 slot for 10Gbps drive speed, one SATA Express port, and an additional six SATA 6Gbps ports. This means your storage troubles are entirely covered, regardless of what you decide to do.

There's also access to two sets of internal USB 3 headers, one of which is (brilliantly, we might add) right-angled to allow for easier cable routing and management of that pesky front I/O cable we've all come to hate. And, of course, there's the plethora of fan connectors and additional USB 2 ports. Handy if you're plugging in an all-in-one water cooler such as the Corsair Hydro series or NZXT's Kraken.

For PCIe support, MSI has kindly provided three PCIe gen3 slots for use in 16x0x0, 8x8x0 or 8x4x4, so ideally, you don't want to be pushing more than two-way crossfire or SLI.

BASIC, BUT SOLID

Rear I/O is a little slim on the ground here, but for the price point, that's to be expected. There's access to two USB 3.0 ports, two USB 2.0 ports, a single Gigabit Ethernet, VGA (God forbid you're still using a VGA monitor), DVI-I, HDMI, Optical Audio out, 5.1 audio, a PS/2 port for backwards compatible/lag free gaming and one single USB 3.1 Type C port. It's important to note here that there's only one USB 3.1 port on this motherboard and it's the Type C standard, so it won't work with more traditional USB devices.

The Z97 Gaming 6 is certainly a solid performer when it comes to overclocking, as well as general all-round performance. Although it does take some time to get your head around the UEFI BIOS, we did then manage to overclock the old girl up to a very respectable 4.8GHz, in line with the rest of our motherboard benchmarks, while also still maintaining our memory frequencies at 2,133MHz.

All in all, this motherboard is a fantastic entry-level board to the world of PC gaming. It doesn't come ram-packed with features and as large a software set as some of the other products in this supertest, but it's got more than enough to it for the average gamer.

So, if gaming is your M.O., and you love a bit of the old black and red colour scheme, this mobo is definitely a solid choice. If you have a bit of extra cash in your pocket though, we'd suggest getting the Z97A Gaming 7 or 9 instead, as you'll be much better off in the long run with regards to USB support and general expandability.

VERDICT **8**

MSI Z97 Gaming 6

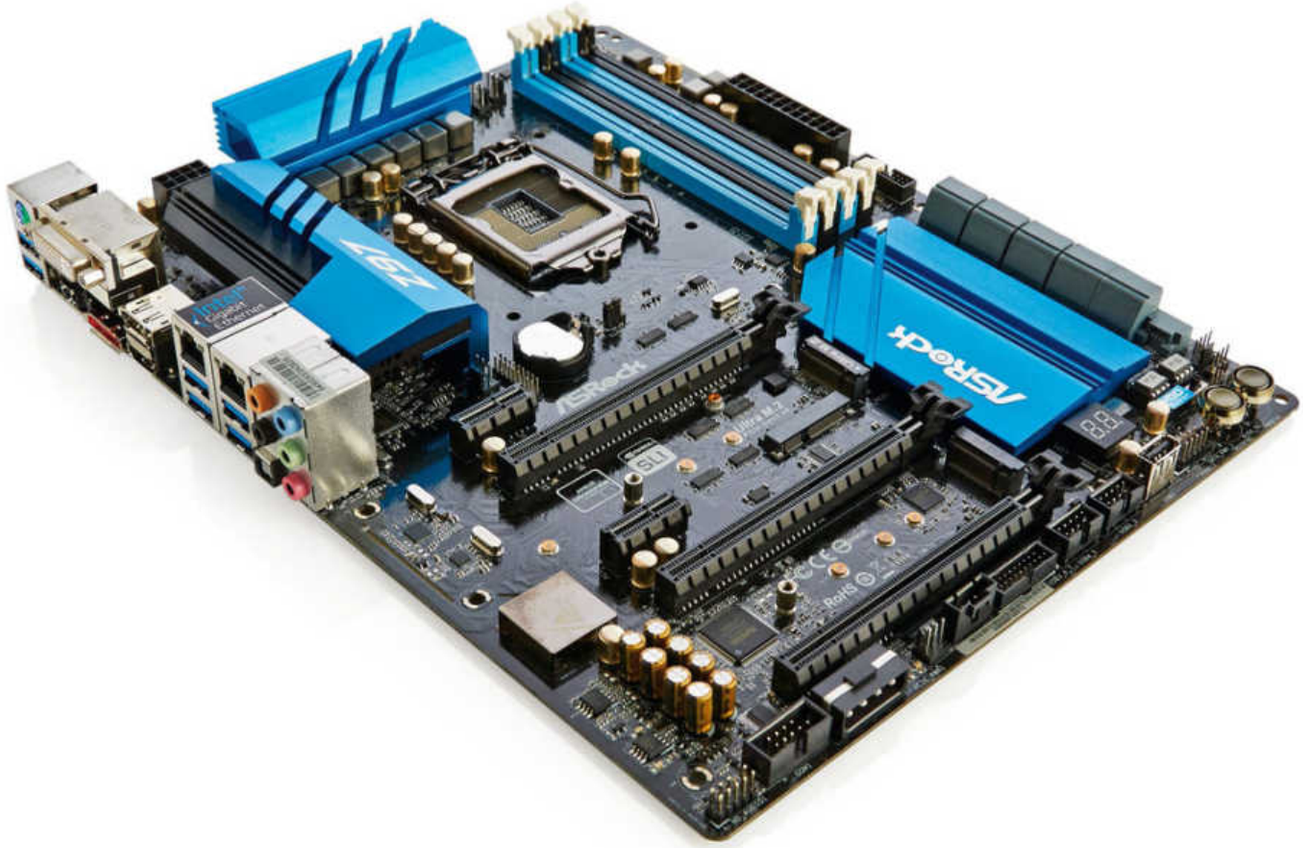
BLOOD RED Great value; performs well; looks great; USB 3.1 Type C; right-angled USB 3.1.

OFF PINK Lacks features; cooling support is limited; difficult install.

£137, www.novatech.co.uk

SPECIFICATIONS

CPU support	Intel X99 / 1150
Form factor	ATX
USB 3.1 support	1x USB 3.1 Type C
M.2 support	1x M.2



ASROCK Z97 EXTREME6

Storage support master defeated by overclocking

WE'VE HAD A BIT of a good run with ASRock in this publication. Our "Overclocking Masterclass" (see page 150) is demonstrated using the Extreme4 edition motherboard, the little brother to this board here. We've also managed to achieve some insane overclocks on ASRock boards, notably 5GHz on its Z77 ITX motherboard, with a tiny little Corsair Hydro H60, so we're expecting big things from this one. Anyway, we digress. This board is the Extreme6, the more feature-rich edition of ASRock's professional line.

ASRock has gone with a blue design style with the latest Z97 and X99 chipset that we all love here. It's nice to see someone else take it on after MSI and Asus seemingly dropped it in the dust after the release of Sandy Bridge. However, unlike the X99 ITX board we reviewed on page 59, you can actually see this board when you place a few items inside the thing.

Internally, this board blows away the competition for storage support. It comes with both an Ultra M.2 Socket, for transfer speeds of up to 32Gbps, and a standard M.2 socket maxing out at 10Gbps. There's a further eight SATA 6Gbps ports and one SATA Express port. For cooling, the pickings aren't as generous. There's access to six on-board fan headers (including the CPU fan), but then ideally you shouldn't be using all of them anyway. We prefer using fan controllers to save on cable mess mostly. For GPU support, you're looking at Quad Crossfire and SLI with three PCIe Gen3 slots. Not that we can imagine many will be running four graphics processors, but the option is there for if you need it.

This board is rammed with additional features, a prime example of why motherboard prices continue to go upwards. HDD save connectors, Thunderbolt AIC connector, BIOS and internal power and reset switches are just a few of the features that helped make the testing for this Z97 go a lot smoother than with many of the others.

Fortunately, due to the premium nature of this ASRock, you're really spoilt for choice when it comes to I/O with two Gigabit Ethernet connectors, DVI-I, DisplayPort, HDMI, six USB 3.0 a PS/2 port and the usual 5.1 audio and optical output. The only downside to this particular motherboard is that USB 3.1 is accessed via a PCI add-on card, though it does feature both 3.1 Type A and Type C, meaning you'll be more than future proofed.

OVERCLOCKING FAIL

Unlike our other boards in this supertest, the Extreme6 failed to achieve the 4.8GHz on our Core i7-4790K. No matter what we did, we just couldn't achieve our standard overclock for the Core i7. This is a shame considering how well ASRock's motherboards have overclocked in the past. At max, we managed an overclock of 4.6GHz, which still produced some good benchmarks, but nowhere near the others in this category.

For the price, the Extreme6 is a tempting purchase, no doubt. With features and connectivity that you'd be expected to pay upwards of £180 for from other manufacturers, we'd be hard-pushed to suggest any other board for those wanting to get into the USB 3.1 market.

For professionals who aren't prepared to buy into the 2011 socket just yet, there's no question. It has an incredible range of storage support and expandability, it's a stable choice, and, even though it may lack the overclocking potential of some of the other boards, it's still a good buy.

VERDICT **7**

ASRock Z97 Extreme6

PROFESSIONAL Storage capacity; looks great; fan support; good value.

RANK AMATEUR Doesn't overclock well; BIOS problematic; USB 3.1 add-on card.

£142, www.ebuyer.com

SPECIFICATIONS

CPU support	Intel Z97 / 1150
Form factor	ATX
USB 3.1 support	1x USB 3.1 Type C 1x USB 3.1 Type A
M.2 support	1x M.2 1x M.2 SSD 1x M.2 Ultra

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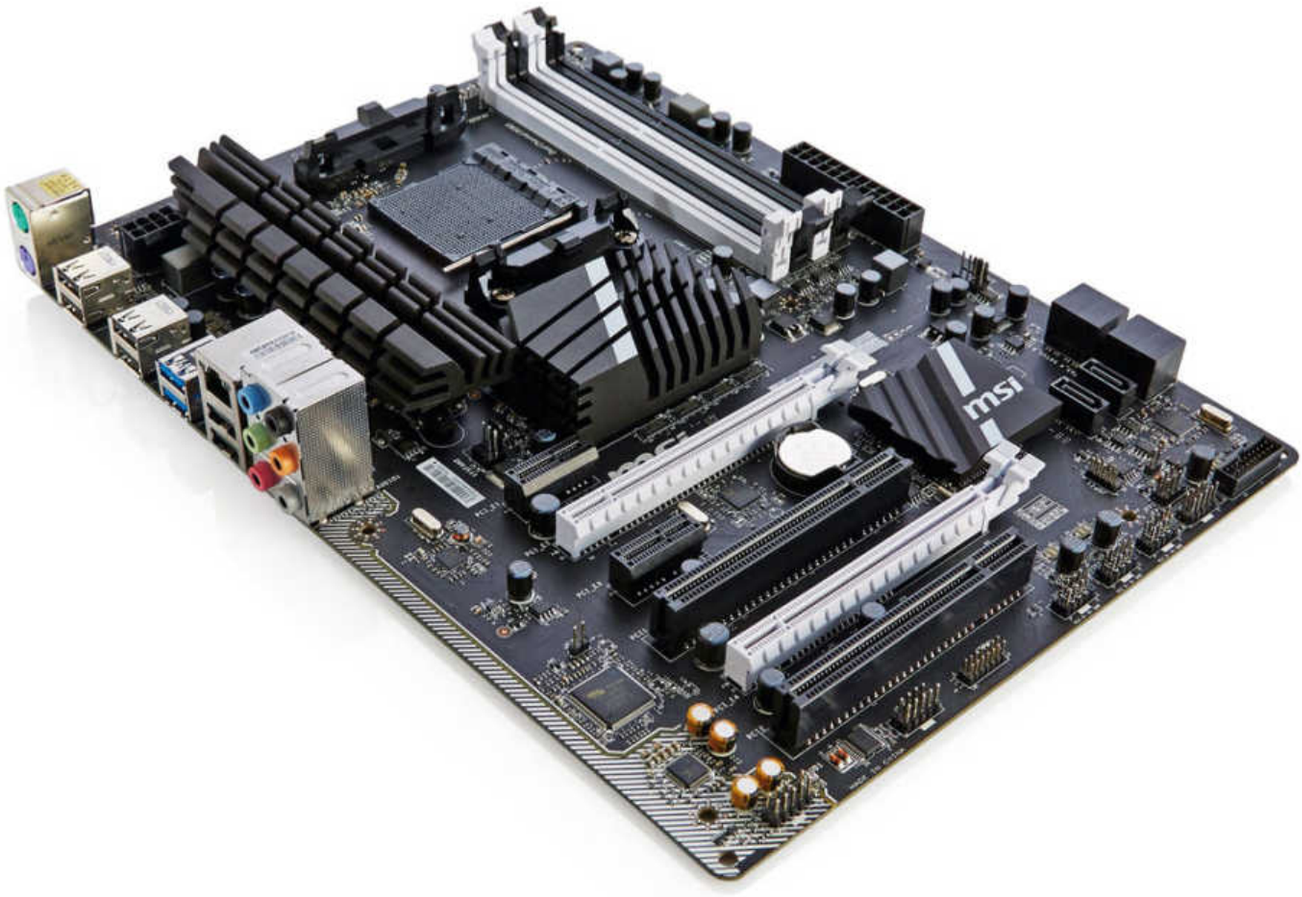


MSI 970A SLI KRAIT EDITION

Beginner board hampered by ageing chip

ONE SIMPLE QUESTION always hounds those who are about to embark on the creation of a new PC – do you go Intel or do you go AMD? Usually, those who are new to the world of PC gaming tend to opt for Intel. That's at least partly down to how easy it is to identify what is new and what isn't with Intel, a route that AMD hasn't chosen to follow. Each time AMD releases a new CPU, instead of forcing a new chipset, it makes sure it's backwards compatible so its customers don't have to change out their motherboards. Decidedly then, this can become quite challenging to find out which AMD boards are new and which are old.

And so to the matter at hand. MSI has brought to the table this visually-arresting M3+ 970 board. Featuring a unique black and white colour scheme, we already have a plethora of build log ideas for how to best take advantage of the looks of this 970A. It's certainly nice to see MSI pushing out new motherboards for AMD sockets, especially ones that look as good as this. It would also go quite nicely with MSI's Krait Edition GPU line as well.

Because of the low price point though, the Krait suffers from a lack of options in regards to internal expandability, supporting only two-way graphics fun, through PCIe Gen2. This is mostly down to the limitations of the AM3+ platform and a CPU dating back to 2011.

Storage is taken care of by six SATA 6Gbps ports, and that's about it. There are three fan headers, including the CPU socket, but besides the usual mix of USB 2.0 ports and two front USB 3.0 ports, that's all she wrote. If you're looking to put together a water-cooled build, or are including this mobo in an airflow-optimised case, you may want to invest in a fan controller to help solve this situation.

OLD ONES AREN'T THE BEST

External I/O is a slightly better story, where the interesting magic happens with the new USB standard. MSI has provided two USB 3.1 Type A ports, which allow for transfer speeds of up to 10Gbps, though this is only supported by MSI's proprietary drivers. On top of this, there's an additional six USB 2.0 ports, one Gigabit Ethernet, two PS/2 ports, and then the standard audio connectors, but no optical output for those that utilise high-end audio.

Performance is intriguing on this Krait. The 970 chipset isn't one that's generally designed around overclocking. However, MSI has included a nicely skinned UEFI BIOS to help those who are interested in doing a little bit of overclocking on the board. Otherwise, you're a little limited. But again, this is primarily down to the AMD CPU already being four years old at this point and not supporting features such as PCIe Gen3, or even memory frequencies above 2,133MHz.

The major problem we found, however, when even attempting to overclock AMD's CPUs, was the heat output. It simply wasn't particularly easy for us to achieve a sustainable overclock that we felt comfortable with on a single radiator AIO water cooler.

But then you have to remember that this board comes into the market at just over £70. In this regard, it's a fantastic entry-level gaming motherboard for those looking to get into the PC gaming scene. It comes with expandability to support two-way crossfire or SLI, and generally will keep you running with some basic expandability for future upgrades. But if you're looking for a competitive, feature-rich board, this isn't the one for you.

VERDICT **6**

MSI 960 SLI Krait Edition

LIGHTNING STRIKER Fantastic colour scheme; USB 3.1 support; software skins.

MARSHMALLOW No M.2 Support; limited SATA support; rear I/O is lacking; AMD CPU is ageing.

£75, www.kikatek.com

SPECIFICATIONS

CPU support	AMD 970 / AM3+
Form factor	ATX
USB 3.1 support	2x USB 3.1
M.2 support	N/A

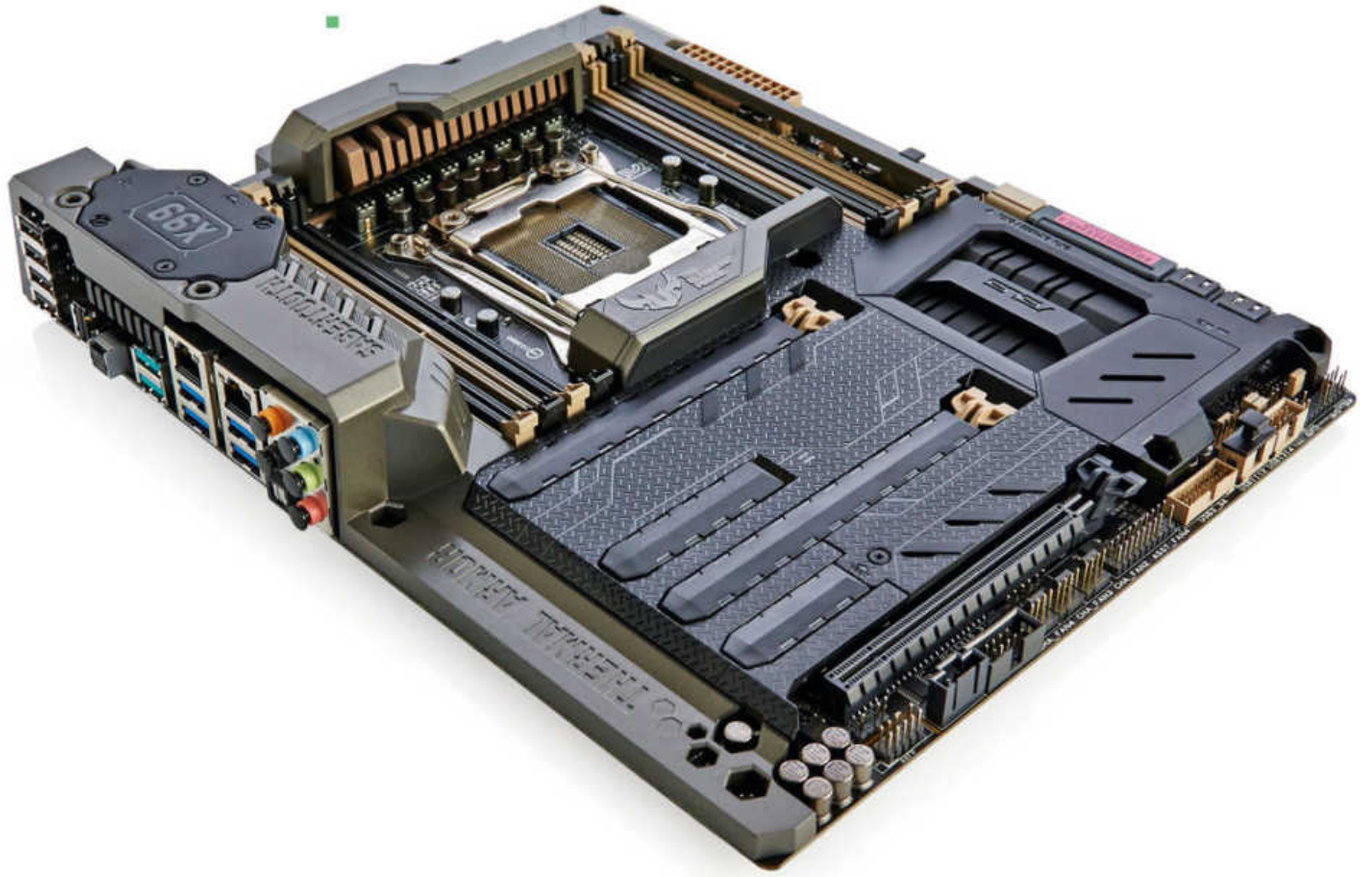
BENCHMARKS

	Asus X99 TUF Sabertooth	ASRock X99 E-ITX	MSI Z97A Gaming 6	ASRock Z97 Extreme6	MSI 970 SLI Krait Edition
Cinebench R15 (index)	1,016	995	873	839	507
x264 (fps)	22	22	19	18	12
SiSoft San memory bandwidth (GB/s)	39	25	20	17	22
AS SSD sequential read (MB/s)	495	495	488	359	479
AS SSD sequential write (MB/s)	346	351	344	333	337
PC Mark (index)	4,082	4,029	4,216	4,239	3,046
OC Cinebench R15 (index)	1,267	1,253	965	917	N/A
OC PC Mark (index)	4,236	4,484	4,520	4,421	N/A

Overall winner is highlighted. All tests were run on the same hardware, using a GeForce GTX 980, 8GB of DDR3 2,133MHz RAM, Corsair Neutron SSD and NZXT Kraken X61 CPU cooler. The X99s were tested with an Intel Core i7-5820K and 16GB of 2,133MHz DDR4; Z97s with a Core i7-4790K; and the AMD 970 tested with an FX-8320E.

SPECIFICATIONS

	Asus X99 TUF Sabertooth	ASRock X99 E-ITX	MSI Z97A Gaming 6	ASRock Z97 Extreme6	MSI 970 SLI Krait Edition
Chipset	Intel X99	Intel X99	Intel Z97	Intel Z97	AMD 970
CPU support	2011	2011	1150	1150	AM3+
Form factor	ATX	E-ITX	ATX	ATX	ATX
USB 3.1 support	2x USB 3.1 Type A	2x USB 3.1 Type A	1x USB 3.1 Type C	1x USB 3.1 Type C 1x USB 3.1 Type A	2x USB 3.1
M.2 support	M.2 PCIe SSD	Ultra M.2 PCIe SSD	1x M.2	1x M.2; 1x M.2 SSD; 1x M.2 Ultra	N/A
Website	www.overclockers.co.uk	www.lambda-tek.com	www.novatech.co.uk	www.ebuyer.com	www.kikatek.com
Price	£286	£240	£137	£142	£75
Score	9	7	8	7	6



And the winner is...

ASUS X99 TUF SABERTOOTH

THERE'S NO SHADOW of a doubt that if you're looking for a motherboard that hits all the marks, Asus's TUF X99 is a solid board. Not only is it a mean-looking workaholic, it also comes packed with more features and cooling support than you could shake a braided cable at. Asus's TUF ICe fortifier is a fantastic piece of componentry in itself, improving cooling performance and fan curves to a degree that's comparable to most aftermarket fan controllers. Granted, it's quite the pricey mobo, but the fact Asus has managed to get so much onto a single motherboard, and still keep it looking so clean, is not something to be shunned.

ACROSS THE BOARD

The ASRock X99 ITX is a remarkable feat of engineering by the Taiwanese company. Unfortunately, however, so much of what makes the Extreme Edition processors so enticing and so powerful has been given up for the sake of hitting that tiny form factor. Two DIMMs, three fan controllers and a lack of support for serious storage is this motherboard's greatest downfall. Even with ASRock doing the best it can with the situation it's been given, the solutions just aren't competitive with other motherboards of its class. It just doesn't make sense in the marketplace. It's not a gaming motherboard, it's not a workstation-class board, it's not even a server-grade board. So what is it?

That said, its other USB 3.1 offering here, the ASRock Z97 Extreme6, provided us with another innovative solution to the USB 3.1 dilemma. Maybe it's possible to overcome all these problems by just including a PCI USB 3.1 add-on card. Although not the most gracious of all the implementations we've seen here, it's certainly the most expansive, including both USB 3.1 Type A and Type C connectors, something none of the other boards featured. Unfortunately, even disregarding the somewhat flaky implementation of the USB 3.1 add-on card, the Z97 Extreme6 just couldn't produce the goods when it came to overclocking. If it can't even handle our stable overclock, we're concerned about what sort of general longevity this board will be able to achieve.

The alternative to the Extreme6 is MSI's Z97 Gaming 6, and although it came in at a moderately attractive price point for an Intel motherboard, it felt a little lacklustre for looks and features. Something that wasn't mentioned in the review was the difficulty we had getting anything to work without drivers, including the Gigabit Ethernet, among other things. But generally, the board just couldn't cut it in comparison with the Asus TUF X99. More so than the ASRock Z97, but still. It remains a great entry-level board to get yourself into the Intel PC gaming scene, but worth an upgrade for its USB 3.1 features alone? Sadly not.

SHOWING ITS AGE

Finally, we get to MSI's 970 Krait SLI Edition, a board that while looking stunning, was mostly held back by the socket it supports. Really, there's not a lot we can say about this one. If you're interested in upgrading within the AMD FX platform, then sure, this is definitely the board you want to get – it looks good, and caps out on all of the features you can get on AMD's painfully ageing four-year-old CPUs. AMD's platforms just feel too dated.

All of which means the Asus X99 TUF Sabertooth remains the best motherboard you can upgrade to if you're on the 2011 platform already, or are considering moving upwards to the Extreme Edition processors. You're truly spoilt with the features that this board provides. Yes £280 is a chunk of cash for a motherboard, but it's well worth it. ■

> **Not only is it a mean-looking workaholic, it also comes packed with more features than you could shake a braided cable at.**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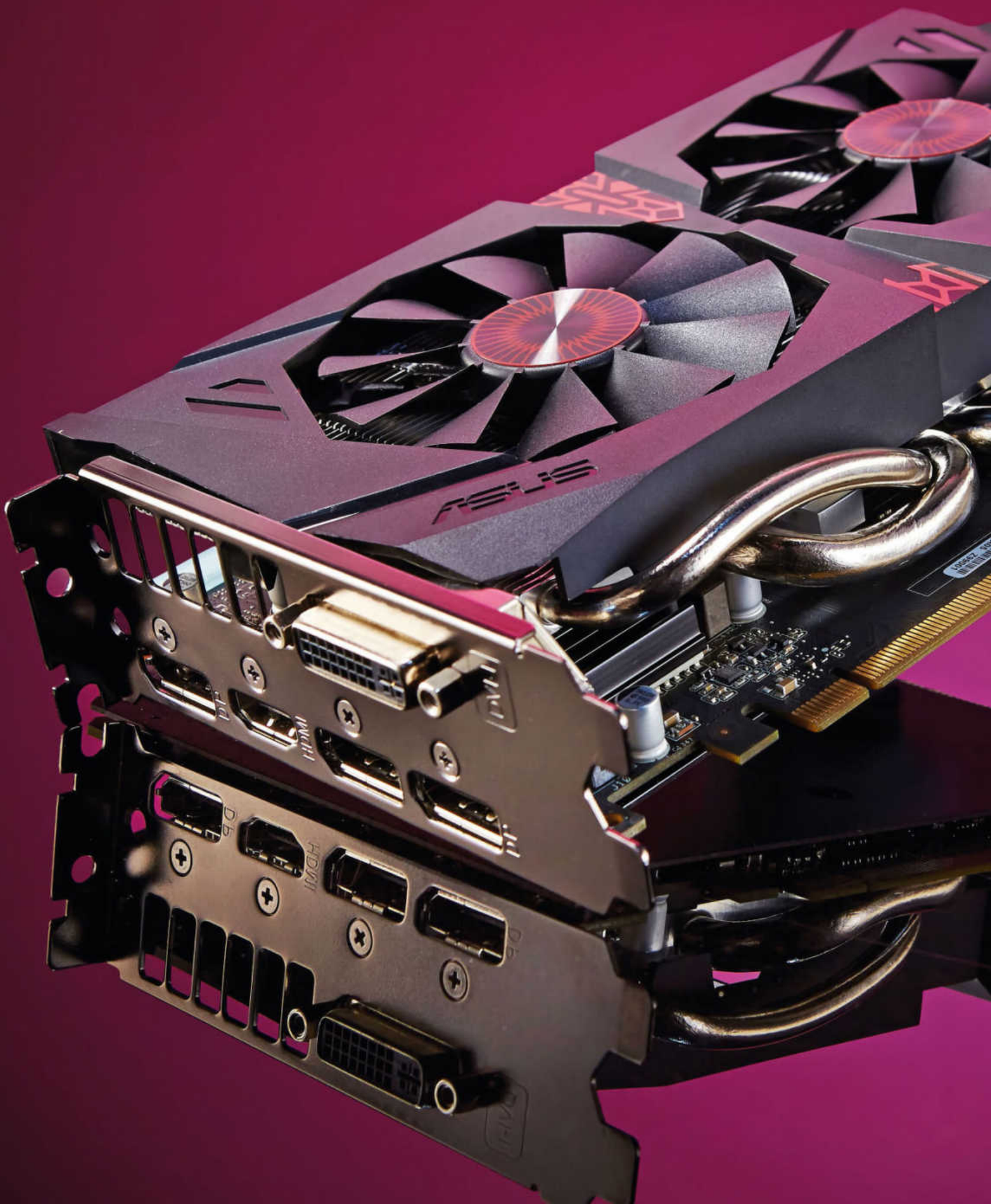
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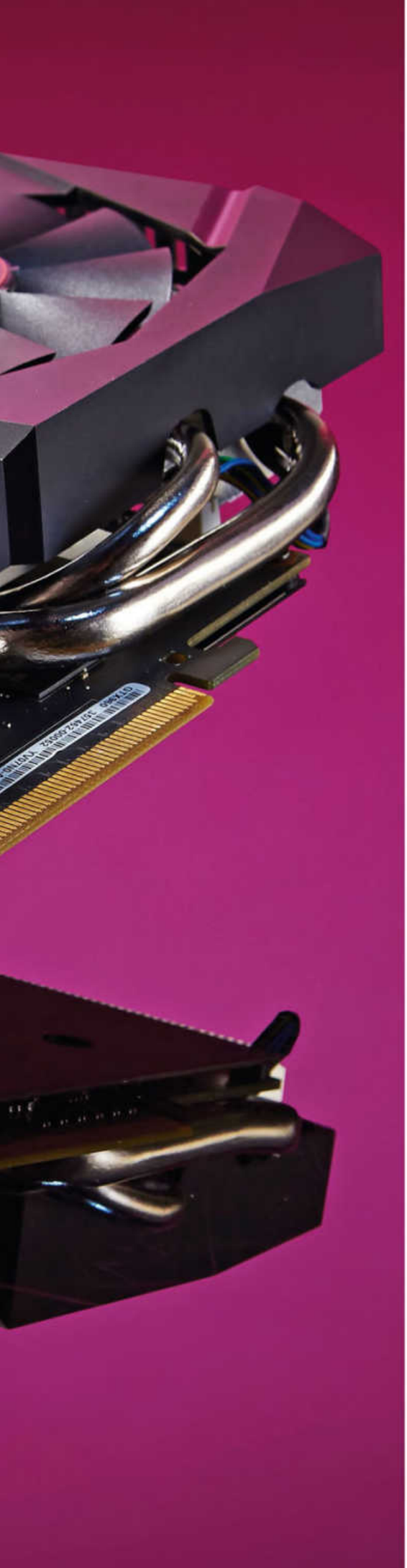


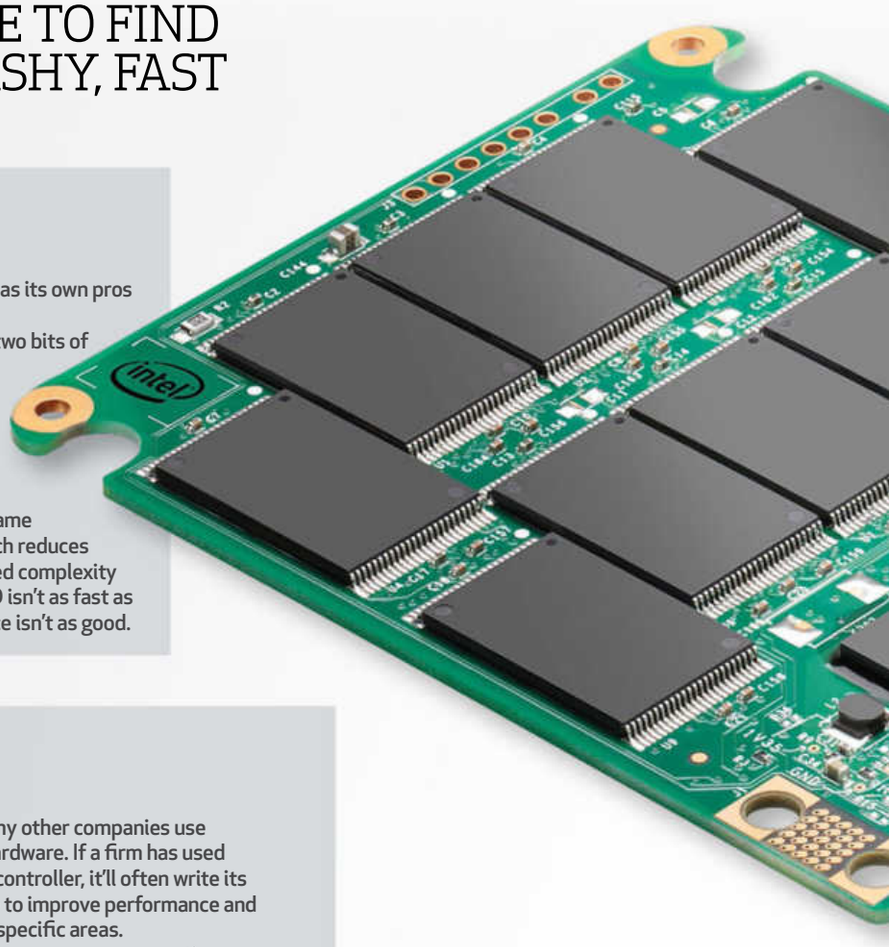
THE ULTIMATE
PC Building HANDBOOK

KILLER COMPONENTS

THE REST OF THE STUFF YOU NEED TO COMPLETE YOUR KILLER RIG

ANATOMY OF AN SSD

WE CRACK OPEN THE CASE TO FIND OUT WHAT'S INSIDE A FLASHY, FAST SOLID-STATE DRIVE



✓ NAND

This is the flash memory that forms the basis of every solid-state drive. It's similar to the memory used for computer RAM, but with one difference – it retains data, rather than losing it when power is lost.

SSDs are built using different types of NAND. The two most common are MLC and TLC – the former acronym stands for multi-level cell, and the latter represents triple-level cell. The names indicate the amount of data and the number of voltage levels stored in the cells that make up NAND chips, and each type has its own pros and cons.

MLC chips contain two bits of data per cell and four voltage levels, while TLC chips double these figures. The increased capacity of TLC means more data can be stored in the same amount of space, which reduces price, but the increased complexity means that TLC NAND isn't as fast as MLC, and its endurance isn't as good.

✓ Controller

This crucial chip handles the flow of data in and out of a solid-state drive – which means it's the most important part of the product, after the NAND flash chips themselves.

It's a small, innocuous component soldered to the SSD's PCB, and it's a processor in itself – most use ARM technology which isn't far off that used in smartphones, and top controllers have two or three processing cores.

Controllers are sometimes produced in-house – Samsung and Toshiba build their own – but many other companies use third-party hardware. If a firm has used a third-party controller, it'll often write its own firmware to improve performance and endurance in specific areas.

Controllers manage every operation performed by the SSD: writes, reads, checking for errors and more. Some SSDs also encrypt data automatically for added security – if a drive has this feature, that's another task handled by the controller.

✓ Endurance

The lifespan of SSDs has become a heated battleground, and it's important to consider longevity if you're planning on spending a significant amount of cash on a new drive.

It's a minefield, because faster SSDs can wear out their flash with increasing rapidity. That's because smaller cell structures are more liable to leak electric charge, which causes various disturbances inside flash chips – all issues that can shorten the lifespan of a drive. Endurance is particularly important in professional scenarios, where computers often read and write huge amounts of data on a daily basis. Home users should be less concerned about wearing out a drive, though – they don't typically churn through the huge amount of read and write data that's required to get near these levels.

New drives are usually given endurance ratings by their manufacturer. These are measured in terabytes, and current drives range anywhere from 35TB to 150TB.

✓ Form factor

Solid-state drives don't rely on the metal platters that are used in traditional hard disks – instead, their flash chips are many times smaller.

That means that SSDs themselves are much smaller than standard hard disks. They're built using a 2.5-inch wide form factor – an inch narrower than desktop hard disks, and equal to mobile hard disks – and they're just 7mm thick. That's 2.5mm thinner than

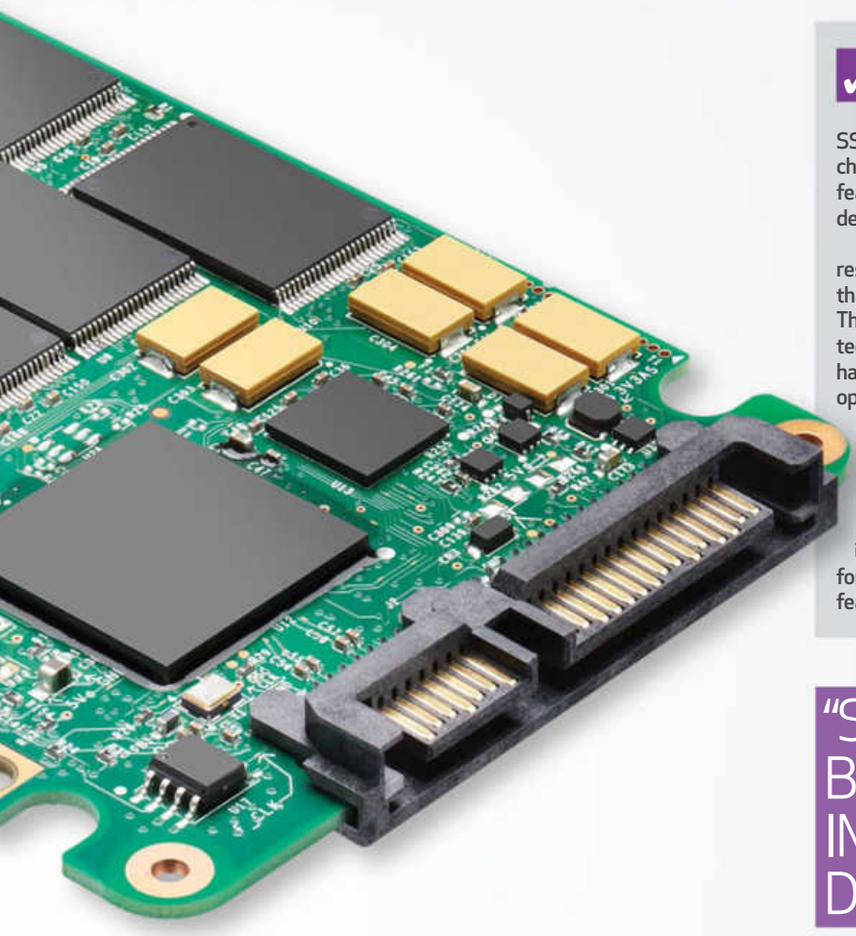
SATA connections

Most SSDs connect to PCs using the SATA ports that are installed on the motherboard. There are two different types, which look similar, but it's important to distinguish between them – otherwise your SSD won't run at its top speed.

The older SATA 2 standard has a maximum potential throughput of 300MB/s, which is absolutely fine for traditional hard disks and optical drives – but that's only half the read and write pace offered by top SSDs.

Instead, look for the motherboard's SATA 3 sockets. They've got a maximum throughput of 600MB/s, which is more than most SSDs can offer. Only the fastest and most expensive drives are beginning to approach this figure.

Motherboards generally include several SATA 2 and SATA 3 sockets, and the different connectors are usually colour-coded. Many manufacturers also indicate which ports use SATA 3 by writing their names on the motherboard, too.



Software features

SSDs aren't just about NAND chips and controllers – software features help the latest drives deliver lightning-fast speeds.

The controller has its own reserved space on each drive that's used for over-provisioning. That name refers to several techniques that the controller handles for performance optimisation, such as junk file management.

Less than a quarter of a drive's capacity is usually reserved for over-provisioning, and it doesn't impact on the space available for users – drives with this feature have larger capacities to allow for this inaccessible partition.

Wear-levelling is designed to automatically arrange data evenly across the drive, so reads and writes aren't concentrated in one area. It's a neat technique that means single flash chips don't wear out before the rest.

TRIM is another feature that's common across most commercial SSDs. It's a feature that tells a computer's operating system when redundant data is still being held on the drive, and works with the controller to write new data to the SSD more efficiently – another feature that improves performance.

"SSDS ARE ALREADY FAST, BUT INSTALLING TWO AND IMPLEMENTING RAID CAN DELIVER A SPEED BOOST"

the first generation of SSDs, and it means that these drives can fit just about anywhere.

SSDs are already moving towards even smaller form factors. The mSATA and M.2 standards are newer, and drives that use these are only a few centimetres long, and barely three millimetres thick. Both attach to slots that are being included on an increasing number of new motherboards.

RAID levels

This storage technique is used to add versatility in systems that use two or more SSDs – and it works with hard disks, too. RAID stands for redundant array of independent disks, and it's designed to manipulate how multiple drives work together to increase read and write speeds – or to improve the security of your data.

There are many RAID levels, but the most common are 0 and 1. RAID level 0 creates a striped volume, which splits data across two or more drives. That means a PC benefits from accessing two disks at the same time – so, in theory, the PC can enjoy double the transfer speeds. RAID 0 improves performance, but it's poor for security; one drive failing can lose an awful lot of data. That's where RAID 1 comes in. Using this kind of RAID setup creates a mirrored array, which copies data from a first SSD on to a second. It's no faster than using one SSD, but it's a good way of reliably backing up all the data from a first drive.

SSDs are already fast, but installing two and implementing RAID can deliver a healthy speed boost – as long as you've got the cash. ■

Super-Speed Storage

What's the best storage option for you?

Once upon a time, there was just one simple solution when it came to computer storage. The ever-reliable, infallible spinning hard drive. That signature sound of those platters whirring into life undoubtedly roused the spirit of many a gamer, knowing that within mere tens of minutes they would be sitting comfortably, ready to load their favorite 32-bit game. It was a technology that, although archaic by today's standards, developed exponentially for its time. First there was IDE, then there was SATA, then the second generation of SATA, and finally SATA revision 3.0, the pinnacle of SATA technology. An interconnect designed and developed to help support and provide compatibility for all future storage devices and drivers, for the next generation of HDD devices.

But something happened, an event that would shape mankind throughout the ages. An event we like to call SSD-Gate. Actually, no, that was a lie. A bad one. We just made that up. But still, it was pretty revolutionary. In 2008, Intel released the X25-M SSD, one of the first commercially available SSDs. Featuring mind-blowing speeds of up to 250MB/s read and 100MB/s write, PC enthusiasts were hooked, and so the craze began. Soon we would all be running the typical combo—as SSD storage was so ridiculously expensive at the time, the most common setup was to use an SSD for your OS and a traditional hard drive for all your games, media, and other files. However, even SATA 3 had its limits. Eventually SSD speeds would overtake that now aging platform, decrepit well ahead of its time, forcing the powers that be to find new and inventive ways around this annoying problem.

Fast-forward to 2015, and the nature of the beast has changed entirely. It turns out that manufacturers don't like bottlenecks. Indeed, they hate them. We now live in a time when there are RAID 0 arrays, M.2 drives, PCIe cards, and all sorts of future tech right around the corner that makes the revolutionary SSD look as good as Donald Trump's "hair." Forget Moore's law, let's talk about SSD speed and capacity acceleration. And which wonderful and lovely storage options are available to you today? Which one should you choose? And how much bang are you getting for your buck? Read on to find out more....


SAMSUNG
Solid State Drive
intel
Act
1 2
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NETGEAR

OVER THE LAST 20 YEARS, storage has changed. A lot. From hard disks and IDE connectors to all three generations of SATA, ultimately it's always been the connection standards that have been the bottleneck

When SATA 6Gbps was first developed, it wasn't expected that we would reach today's speeds so quickly. Indeed, with SSD and NAND flash far outstripping SATA 3's rated connectivity speeds, it seems far-fetched to believe that SATA 3 would have kept us going for this long. And so, as is often the way when PC enthusiasts are presented with a bottleneck, the manufacturers tried to find solutions around this gargantuan wall, to pry our hard-earned cash out of our wallets and into their pockets.

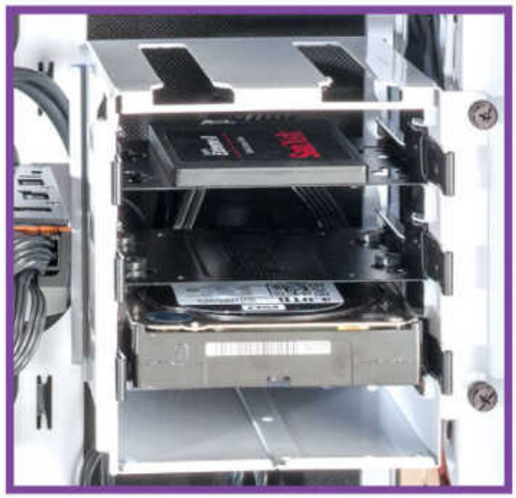
The initial quick-and-easy solution was to use an old trick: the RAID array. More often than not used for redundancy rather than speed, RAID 0 provided break-neck connectivity by splitting data and files in half between two disk drives, theoretically allowing data to be pulled off both of the drives at the same time.

Then came the push to utilize PCIe, an interface that we still haven't managed to saturate. You can easily transfer upward of 120Gbps, nearly 20 times more than SATA 3.

After that came M.2, a smaller form factor laptop drive originally designed to operate in a similar way to mSATA. The M.2 interconnect had one particularly interesting asset: it integrated directly into the PCIe bus, giving it the ability to take full advantage of the expanded bandwidth and increased speeds of that platform, increasing NAND flash performance almost fourfold. Impressive.

DEPENDENCY

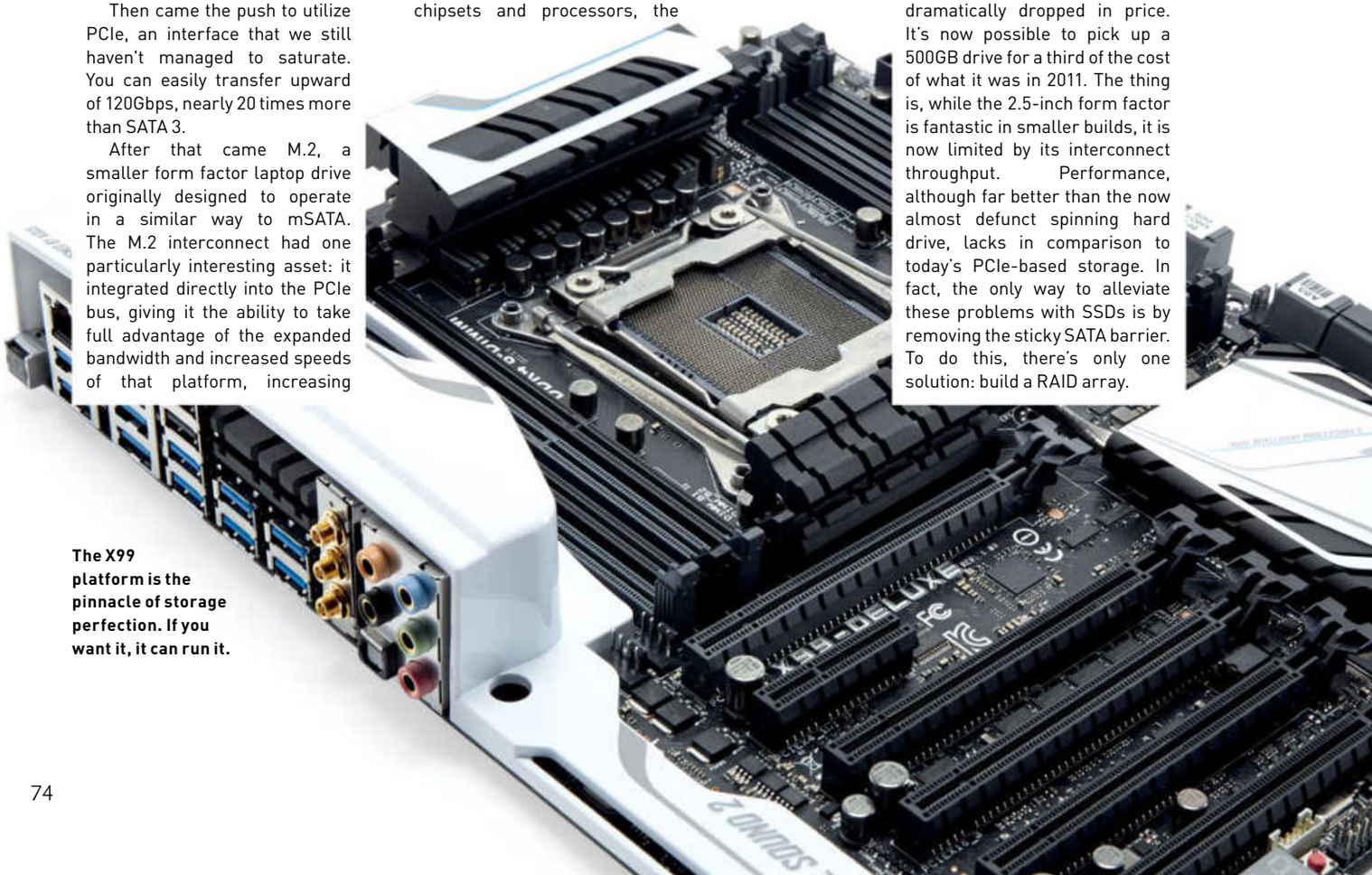
Ultimately, storage connectivity has always depended on one component—the motherboard. The more modern the motherboard, the more likely you are to be able to support these new storage standards. Intel's latest Skylake chipset, the Z170, supports 20 PCIe 3.0 lanes. This is in direct response to the increased number of people using those same PCIe lanes for storage as well as graphical horsepower. Because the storage utilizes PCIe lanes, you lose out on the number of lanes available for your GPUs—in some scenarios, if you're using SLI or Crossfire, it may not be possible to install an M.2 PCIe card without the additional lanes provided in the latest Z170 chipset. With Intel increasing the number of PCIe lanes in its chipsets and processors, the uptick of PCIe storage seems almost inevitable.



There are always limitations when it comes to storage. Don't believe what they tell you—you can't download more RAM.

OLD-SKOOL SSDS

Unless you've been stuck under a rock for the last three years, you're probably aware that 2.5-inch SATA SSDs have dramatically dropped in price. It's now possible to pick up a 500GB drive for a third of the cost of what it was in 2011. The thing is, while the 2.5-inch form factor is fantastic in smaller builds, it is now limited by its interconnect throughput. Performance, although far better than the now almost defunct spinning hard drive, lacks in comparison to today's PCIe-based storage. In fact, the only way to alleviate these problems with SSDs is by removing the sticky SATA barrier. To do this, there's only one solution: build a RAID array.



The X99 platform is the pinnacle of storage perfection. If you want it, it can run it.

RAID 0 ARRAY There's a plethora of RAID arrays to choose from—however, the most common ones you'll come across are RAID 0, 1, 5, and 10. RAID 0, possibly the most interesting of the four, requires a minimum of two drives

Essentially, the principle is fairly basic: split the data across both hard drives, then read or write off both of them simultaneously to provide an impressive performance boost. The one major downside to this is that if one of your drives fails, you lose all of your information with no chance of recovery. Although in today's climate that's a pretty rare occurrence, it's still advisable to keep the vast majority of your valued files offsite. After all, you want to make sure that you've got at least one backup, and ideally you want to have a backup for your backup as well—we wouldn't want to be around when your primary system and your backup fails. Heh, *Star Trek*.

Anyway, back to the point: keeping your OS and some games on your array is often the best solution, especially in today's modern age of cloud storage and super-fast download speeds, when reinstalling an OS doesn't take a week.

To set up and install a RAID 0 system, you need to use your BIOS, Intel's Rapid Storage Technology, and at least two drives. Instructions can be found in your motherboard's user manual, however, changing the "PCH Storage" option from "AHCI "to "RAID" should do the trick. Then it's a simple case of rebooting and mashing Ctrl-I to get into the Intel Rapid Storage Driver, and creating your RAID array from there.

SPEED SPECS

As you can see from our benchmarks on page 78, our array performance is right around where we'd expect to find it. Three Samsung 850 Pros in RAID 0 provide us with a grand total of 384GB of storage, and performance speeds in synthetic benchmarks ranging anywhere from 1,200MB/s to 1,500MB/s read and 1,000MB/s to 1,100MB/s write. This solution really shines in desktop copies and transfers, reducing overall copy time by half, making for a much smoother experience, and an instantaneous response when moving folders with photos.

ALTERNATIVE RAID

But wait, there's more. RAID 0 isn't your only option. RAID 1 uses exactly two drives, and mirrors your data across both at the same time. The benefit here is that if one of your devices fails, there's always a backup. A hardware RAID controller can also potentially read from both drives for improved speeds too.

RAID 5 is a little more complex. It requires a minimum of three drives, and stripes the data across the drives along with a rotating parity block. It detects when there may be problems on either of the other drives and migrating system-critical information from the damaged or decaying drive on to one of the others. This is often used in NAS devices or servers, where multiple people may be using the array at any given time.

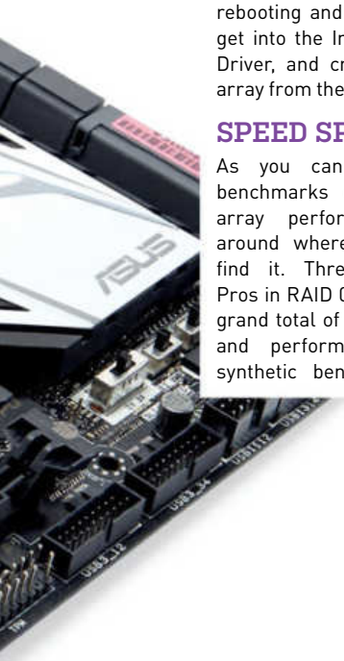
Then there's RAID 10, the king of money spending, storage, and dependability. It takes the best parts of both RAID 0 and RAID 1, and merges them together, simultaneously mirroring and striping the data between the number of drives you have available. You need a minimum of four disks to do this, and you lose half of your storage capacity in the process, but it's the most effective and efficient way to use SSDs—just not for those looking at cost-effective storage solutions.

RAID 0 provides a rapid alternative to storage woes.

Setting up a RAID is as easy as it comes nowadays.

RAID REASONING

Ultimately, RAID 0 provides a cheap, fast, easy, eye-pleasing solution to modern-day storage woes. Although the synthetic benchmark speeds often don't transfer well into gaming scenarios, the snappiness you'll find on desktop file transfers will be enough to make any PC enthusiast crumble. The only problem with it is boot times. If you're looking for a super-fast startup, you're more than likely still going to want to utilize just a single SSD. Intel's rapid storage boot manager does take a considerable amount of time to get past, and even though you benefit from those speedy read times, you're still going to suffer because of it.



PCIE SSDS The most exciting advancement that we've seen over the last year or so has been the continued push into the PCIe SSD—allow us to explain why

Utilizing the PCI Express interconnect to deliver stunning storage speeds is a fantastic step forward, and undoubtedly where the future of storage lies. Originally hampered by insane levels of cost, the price of the PCIe SSD has dropped dramatically over the last year. Indeed, per gigabyte, it's now half the cost of the most expensive SSD. Still sounds like a lot, but ultimately it's far cheaper than when it debuted back in 2012.

Currently, it's around 75p per gigabyte for an Intel 750 SSD, or 70p per gigabyte on Samsung's OEM SM951 versus 40p per gigabyte for a Samsung 850 Pro SSD. But considering you're getting almost four times the performance by using an M.2 drive, it's more than cost-effective and, if SSD prices are anything to go by, it's not going to be long until these drives cost the same as SSDs do today.

AVAILABILITY

Hardware and connection speeds haven't been the only problems manufacturers have had to face. In fact, they're only the start. The biggest conundrum has been how to surpass the aging AHCI protocol. Essentially a software interface to help convert the physical interface's information, AHCI was designed for spinning drives and high-latency devices—nothing comparable to today's NAND flash storage. Although SSDs still work quite efficiently on this, a new software interface was needed. Welcome to NVMe, a collaborative project worked on by over 80 members of a consortium, directed by Samsung and Intel. NVMe (Non-Volatile Memory Express) was designed to work with both SSDs and PCIe going forward.

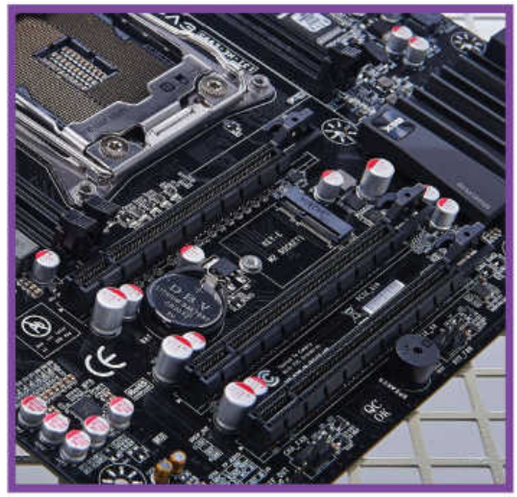
AESTHETICS

Ultimately, the biggest problem in the enthusiast arena has been aesthetics. When manufacturers first introduced their lineups of PCIe SSDs, they came covered in a lovely shade of green PCB. On top of this, you lose out on a PCIe slot, which for more aesthetically minded system builders, can ruin the look of a good build.

M.2 PCIe drives do little to alleviate the situation. Raised above the board, they suffer from the same drawbacks, with the vast majority including that signature shade of grass-green PCB. Indeed, it's only recently, with the launch of Samsung's 950 Pro, that the first all-black consumer-grade PCB has been seen in this department.

U.2 AND 2.5-INCH

So, for a while now, the industry has been looking for a way to improve the connectivity speeds of the traditional 2.5-inch drive, and although M.2 drives are incredibly powerful and efficient, they still have flaws—namely, thermal limitations and drive capacity. Although Samsung has just announced its first 1TB M.2 drive, these devices will no doubt come at a great cost to the user and aren't going to be available in the market until some time later in 2016.



It's all about utilizing those PCIe lanes. Who'd have thunk?

Welcome to SFF-8639. A connection standard that's been used in enterprise-grade systems for some time now, it's finally making its way to the consumer side. Notably with a rename: U.2 (not the band; it's pronounced you-dot-two), bringing it more in line with M.2 and making it a little easier to remember. U.2 still features the same access that M.2 has, utilizing four PCIe 3.0 lines, and still promises the same speed, just in the traditional 2.5-inch form factor. The only downside is that, for the time being at least, the cable is rather bulky, and Intel plus a few other select board partners are the only ones supporting it.

PCIE PERORATION

In the end, these drives are no doubt the future of storage expansion. As more memory chip manufacturers migrate to PCIe-based devices, it's inevitable that these devices, especially those utilizing NVMe, will become the SSDs of tomorrow. With stunning performance, low cost, low power usage, and small form factors, is there any doubt as to which storage solution has won the war?

The Intel 750 SSD is one of the fastest performing drives to date.

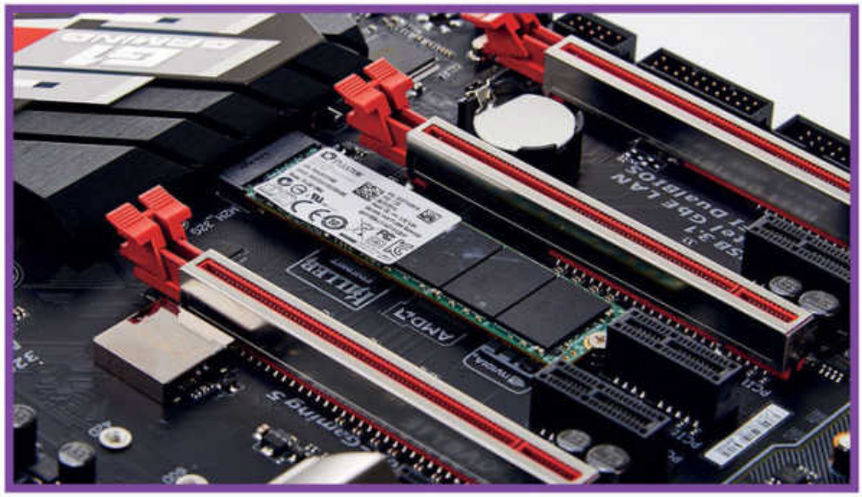
M.2 FORM FACTOR Ahhh, the M.2 form factor, the golden era of computing, following Moore's law admirably—as transistors get smaller and smaller, memory follows suit

With companies such as Samsung and other storage conglomerates pushing memory chips with up to 48-layer V-NAND, it was surely only a matter of time before a smaller form factor storage device was achieved.

Indeed, long gone are the days of clunky 3.5-inch drives. In fact, if you were to buy any modern Ultrabook, there's no doubt that you'd be picking up one of these bad boys with it, whether you knew it or not.

CONSIDER COST

Although we've spoken about M.2 in depth already, there's more than just the traditional all-out speed demons. In fact, you can get M.2 drives that are as fast as today's standard SSDs. Now, we know what you're thinking—why on earth would you want that? Well, simply put, M.2 drives are ridiculously less complicated to build than their 2.5-inch form factor counterparts, and because of this, it makes them extremely affordable and accessible to the vast majority of us. Indeed, you can get your grubby little hands on a Crucial BX100 500GB M.2 SSD for roughly £130, making it the cheapest out of all our storage solutions, at just 26p per gigabyte. Alternatively, the speedier MX200 250GB can be had for £80, or 32p/GB.



Don't let its size fool you—M.2 is more than enough to take on any 2.5-inch drive.

The downside is motherboard and device compatibility. You'll need to ensure your motherboard has at least one M.2 slot, that it can support the size of M.2 drive that you're going to purchase, and that you're willing to give up those PCIe lanes as necessary. Additionally, there's a whole assortment of NGFF (next-generation form factor) sizes, depending on your needs, ranging from 2242, 2260, and 2280, all the way up to 22110—although, to be honest with you, we haven't even seen the latter sized drive.

M.2 MATTERS

There's another downside to M.2, and that's how it looks. With only a select few companies utilizing black PCBs, they can stand out rather dramatically in comparison to the more traditional SSD. They do, however, provide a fantastic solution if you're not bothered about appearances, have a non-windowed case, or are utilizing a NUC or some other small form factor device.

WAIT! WHAT HAPPENED TO SATA EXPRESS?

Well, as you probably already know, SATA 3 has always been the problem child of storage speeds. Hell, we've hit on that enough during this very feature. However, M.2 and tapping into PCIe lanes wasn't the first solution to the problem. An additional physical interface came in the form of SATA Express. Essentially taking up two SATA 6Gbps lanes and some additional power, it's an interface that enables speeds of up to 1,959MB/s read and write by utilizing the same PCIe lanes that M.2 and U.2 now occupy. Unfortunately, as a standard, it just never took off, certainly not in the way that PCIe storage or SATA originally did.

There were a couple of SATA Express SSDs out there, but nowhere near enough to provide any form of available market. Indeed, companies such as Asus have now taken that interface and even created front-bay devices using USB 3.1 and providing up to 100W of power to find at least something to do with it.

To wrap up serial ATA, we've got to look at mSATA, which stands for mini-SATA. Essentially a smaller form factor SSD, mSATA was most commonly found in notebooks and early small form factor devices before being replaced by the higher speed M.2 devices. It does, however, utilize the SATA host controller, as opposed to the PCIe host controller, meaning you don't lose out on those valuable PCIe lanes in smaller form factor builds. Something that's become null and void over the last year or so.

CONCLUSION And there you have it, folks—that's the vast majority of super-fast storage solutions available to you today, and wow, does it look like a doozie

RAID 0 provides some impressive figures for its low price, but PCIe storage solutions will be the clincher going forward. If it wasn't for the innovations we've seen with manufacturers using the PCIe physical interface, RAID 0 may have taken the win. Alas, its limitations have been reached and spooling more and more drives together isn't a viable solution to our speed woes.

With SSD capacity ever increasing (say hello to 4TB Samsung drives coming soon), it's only a matter of time before they replace the aging hard disks of yesteryear. They're far more responsive, energy-saving, and noise-reducing than their ancient counterparts, and even using the SATA 3 interface, still very potent.

PERSONAL CHOICE

What it comes down to is personal preference and what you need. A 1.2TB Intel PCIe card might be ideal for a workstation-grade computer, rendering 3D models every day, but if you don't need the horsepower or detest the ugliness of the drive consuming another of your cherished PCIe slots, it's probably not the solution for you. M.2 is great for small form factors, but again suffers from the same problem—currently, the only way of hiding these drives is by using a motherboard with thermal armor (here's looking at you, Asus), otherwise you're stuck with it staring you in the face.

RAID arrays are another great solution, less useful for gamers but, all in all, quite easy to set up, and in today's climate, exceedingly stable. In fact, some of our writers have used RAID 0 SSD arrays for years, with little to no problems whatsoever.

FUTURE TECH

All of that being said, this isn't the end of storage speed, and indeed this year saw Intel and Micron announce 3D Xpoint, the first new memory storage technology invented within the last four decades. Touting performance figures 1,000 times greater than traditional NAND flash, and endurance to match, these devices are set to hit the stage sometime in 2016. Although Intel hasn't let on as to how exactly 3D Xpoint works (no doubt in an attempt to fend off potential competitors), roughly speaking, it forsakes the transistor in favor of a resistive material, where the resistance between two points indicates whether the bit of information is a 1 or a 0. Although still not as fast as today's DDR4 (just), the fact it's non-volatile and stackable makes it a potentially revolutionary invention—depending, of course, on whether Intel can bring it to the consumer market. And, of course, we'll need an additional storage interface to be able to even transfer that amount of information, because read and write speeds topping a whopping 550,000MB/s might be a bit much, even for PCI Express.

Traditional SSDs are cheap, and readily available for you to take advantage of.

SSD STILL BEST

So, SSD is still king of the hill. It's still the most diverse storage solution out there today. It has successfully supplanted the old-school HDD and cemented its way into our hearts by being the stealthiest good-looking drive out there. As an interface, U.2 is still far too clunky looking, and for gaming, honestly, you don't need more than that, certainly not for the time being. Perhaps today the best setup is a RAID 0 array for your OS, and then a standard 500GB-1TB drive for your games and media.

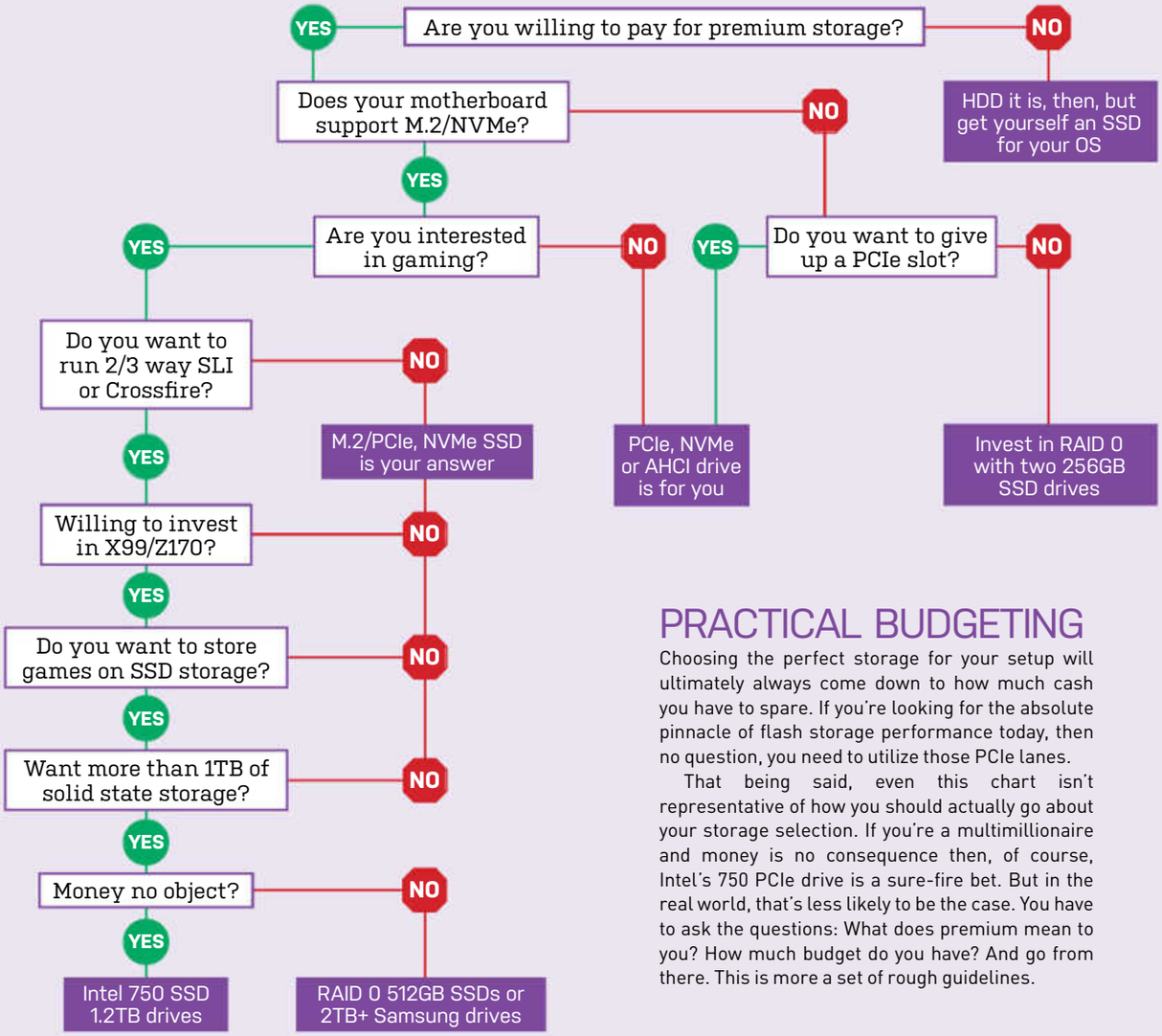
What ever happens, we'll be glad to hear the last of the inevitable whir of a mechanical drive as it spins into history, alongside the great noises of our technological past. Farewell platters, farewell dial-up, farewell motherboard beeps!

BENCHMARKS

	AS SSD Sequential Read	AS SSD Sequential Write	AS SSD 4K 64Thr Read	
3x Samsung 850 Pro 128GB SSD RAID 0	1,505MB/s	1,258MB/s	728MB/s	
Samsung 950 Pro NVMe SSD	2,063MB/s	901MB/s	1,021MB/s	
Intel 750 SSD 1.2TB	**2,201MB/s**	**1,315MB/s**	**1,445MB/s**	
Samsung 850 Pro 2TB	496MB/s	477MB/s	371MB/s	

Best scores are in bold.

Pick the perfect desktop storage for your machine

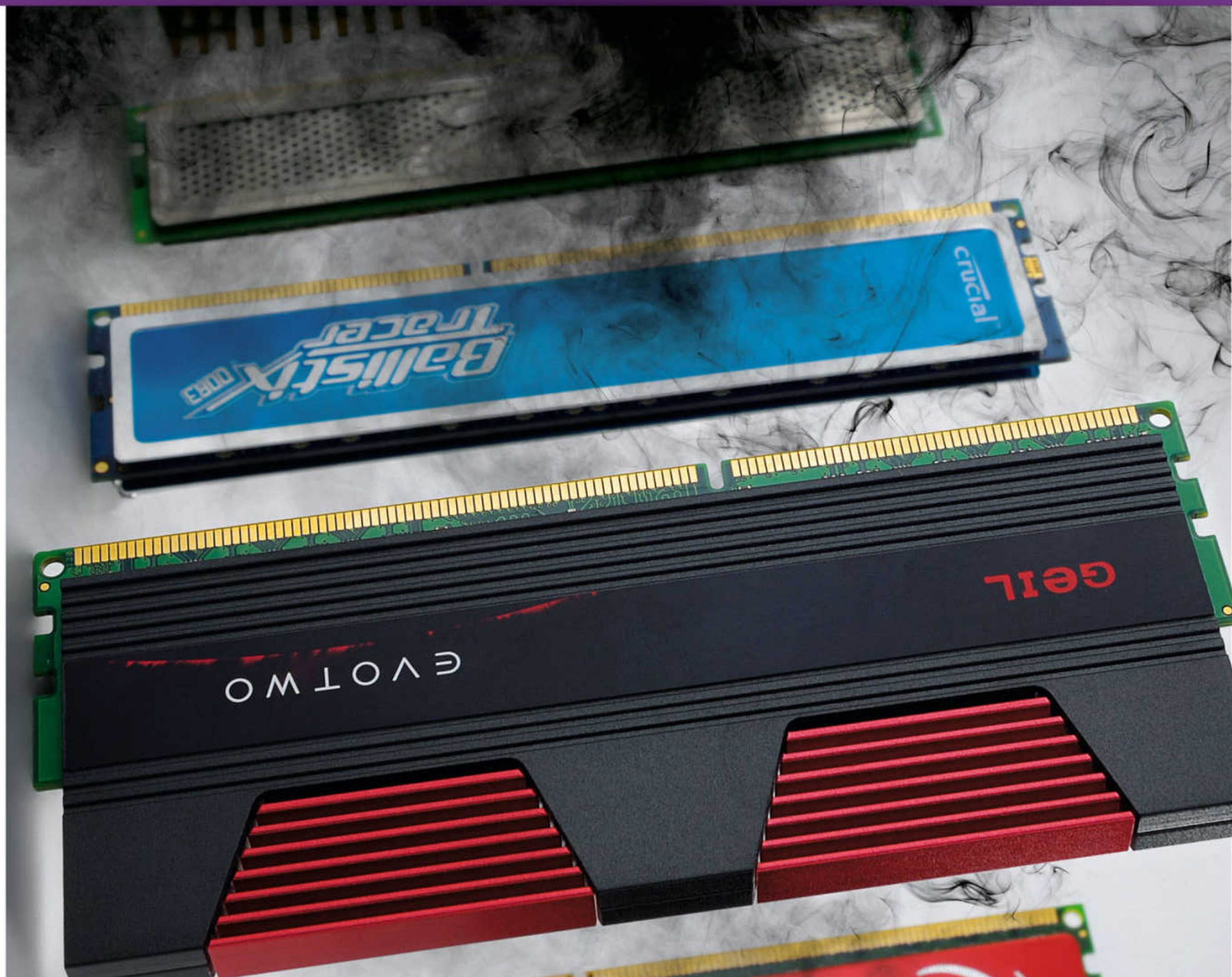


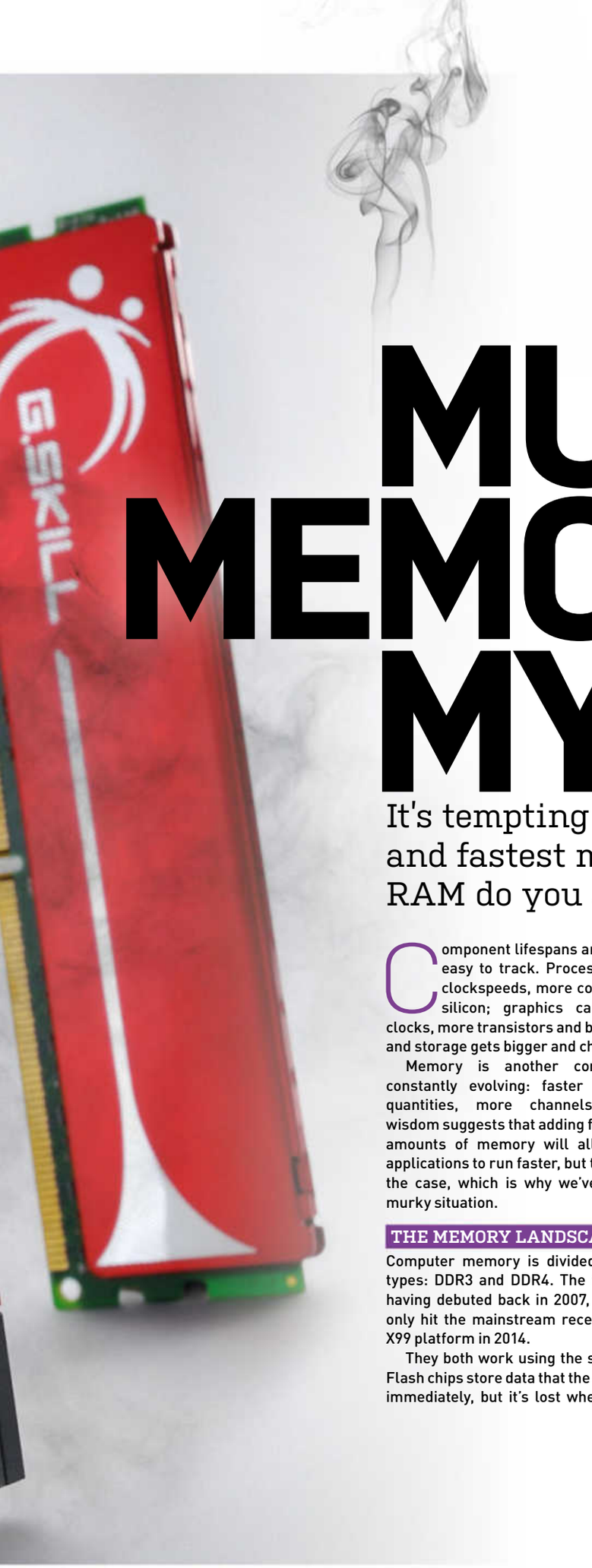
PRACTICAL BUDGETING

Choosing the perfect storage for your setup will ultimately always come down to how much cash you have to spare. If you're looking for the absolute pinnacle of flash storage performance today, then no question, you need to utilize those PCIe lanes.

That being said, even this chart isn't representative of how you should actually go about your storage selection. If you're a multimillionaire and money is no consequence then, of course, Intel's 750 PCIe drive is a sure-fire bet. But in the real world, that's less likely to be the case. You have to ask the questions: What does premium mean to you? How much budget do you have? And go from there. This is more a set of rough guidelines.

	AS SSD 4K 64Thr Write	PC Mark 8 Storage Bandwidth	File Transfer Copy Speed	IOMeter 128K Sequential Average	IOMeter 4K Random Average
	645MB/s	260MB/s	334MB/s	1,019MB/s	124MB/s
	254MB/s	**622MB/s**	560MB/s	1,008MB/s	267MB/s
	1,067MB/s	495MB/s	**564MB/s**	**1,605MB/s**	**454MB/s**
	292MB/s	280MB/s	190MB/s	496MB/s	222MB/s


Ballistix Tracer DDR3
crucial
GeIL
EVO TWO



MUSCLE MEMORY MYTHS

It's tempting to always get the biggest and fastest memory kit, but how much RAM do you actually need?

Component lifespans are usually pretty easy to track. Processors get higher clockspeeds, more cores and smaller silicon; graphics cards get better clocks, more transistors and bigger heatsinks; and storage gets bigger and cheaper.

Memory is another component that's constantly evolving: faster speeds, bigger quantities, more channels. Conventional wisdom suggests that adding faster and larger amounts of memory will allow games and applications to run faster, but that's not always the case, which is why we've examined this murky situation.

THE MEMORY LANDSCAPE

Computer memory is divided into two main types: DDR3 and DDR4. The former is older, having debuted back in 2007, while the latter only hit the mainstream recently, with Intel's X99 platform in 2014.

They both work using the same principle – Flash chips store data that the computer needs immediately, but it's lost when it's no longer useful or the PC is turned off. It's governed by several common attributes: larger amounts mean more data can be stored, and higher MHz ratings mean the memory runs at a faster speed, so data moves in and out more rapidly.

The newer standard, DDR4, has several advantages over DDR3. It runs at a higher frequency, so it's able to process tasks at a faster rate: DDR3 is generally clocked between 1,333MHz and 2,400MHz, while DDR4 ranges from 2,400MHz to 3,200MHz. It's possible to blur these lines with overclocking, but, for the most part, DDR4 is faster. It balances those better speeds with more efficient power consumption, and its chips have double the internal memory banks, faster burst access and higher data transfer rates.

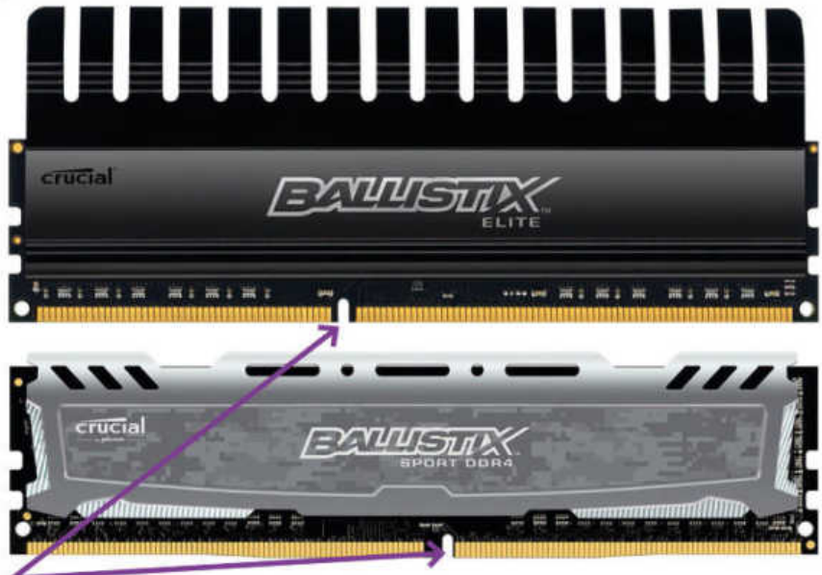
DDR3 and DDR4 memory work with different motherboards and chipsets. DDR3 memory is compatible with virtually every motherboard and socket type you're able to buy right now, but DDR4 memory is only compatible with boards that use Intel's X99 chipset and LGA 2011 processor socket.

DDR4, however, does have one downside. That's increased latency. Newer DDR4 2,133MHz memory has a latency rating of CL15, which means it'll take 14.06ns to perform a read, while DDR3 1,600MHz memory reads at 13.75ns. That's a tiny margin, and DDR4 negates this disadvantage with its generally higher clockspeeds – nevertheless, if you'd like to keep an eye out, look for CAS ratings. This indicates latency, and lower is better.

No matter which memory you buy, you'll have to deal with channels. Dual- and quad-channel setups are the most popular and improve performance by allowing motherboards to use multiple channels to send and receive data simultaneously, therefore improving bandwidth. It's possible to run memory in single-channel mode, but there'll be a performance decrease if you run a single stick of memory rather than two or four.

THE CHANGING PC LANDSCAPE

The variety of different specifications means prices vary wildly. The cheapest 16GB DDR3 kits made from two 8GB sticks currently cost less than £50, but the most expensive can cost more than £200. It's a similar story with DDR4, which dual- and quad-channel kits also vary by huge amounts when it comes to price. But these will always be more expensive than their DDR3 equivalents.



Different locations of the key notch (on the insertion edge of each DIMM) prevents a DDR3 (top) or DDR4 stick (bottom) from being installed into an incompatible board or platform.

"No matter what CPU or mobo you use, you'll be able to equip a rig with high-end memory."

Manufacturers claim that the increased speeds and better features provided by pricier kits will make a dramatic difference to your PC's performance, but we're not so sure – so we've set up some test rigs to find out just how much memory you really need.

Both of our rigs use MSI motherboards supplied by Overclockers UK. One uses Intel's Z79 chipset with a Core i7-4770K processor, while the other is an X99 rig with a Core i7-5820K chip. Both use operating systems installed on a Samsung 850 Evo SSD, and both use an Nvidia GeForce GTX 980 graphics card.

We've already mentioned the different processors and chipsets that work with DDR3 and DDR4, but there's more to choosing components than just making sure your new gear is compatible on paper. Intel's Haswell architecture is behind the bulk of its current desktop processors, and it was its first to include native support for dual-channel memory, with up to 32GB of RAM. It's used for chips that range from cheap Celerons and Pentiums to pricey Core i5s and Core i7s, and these desktop Haswell chips all plug in to the LGA1150 socket.

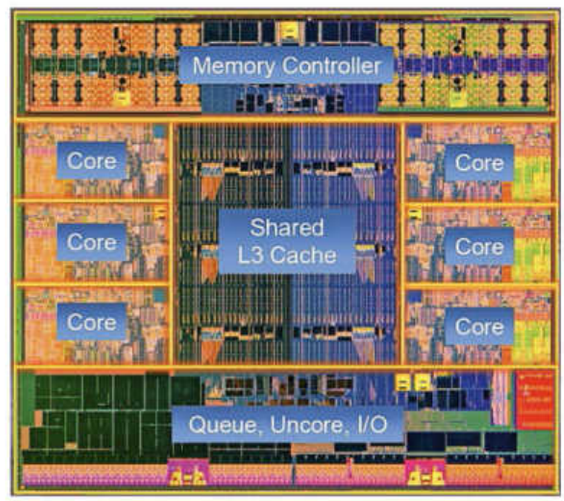
Most Haswell-based processors are deployed with mobos that have Intel's H87, Z97 and Z87 chipsets. When it comes to memory support, they're all impressive: they handle four slots which accommodate two sets of dual-channel memory, and most full-size ATX boards also support 32GB or 64GB of memory at rapid speeds.

Intel has further developed its architecture with Haswell-E. Chips that use this system also use the LGA2011 socket and X99 chipset, which means that support for DDR4 is included – and so, in turn, that means support for faster quad-channel memory when compared to DDR3.

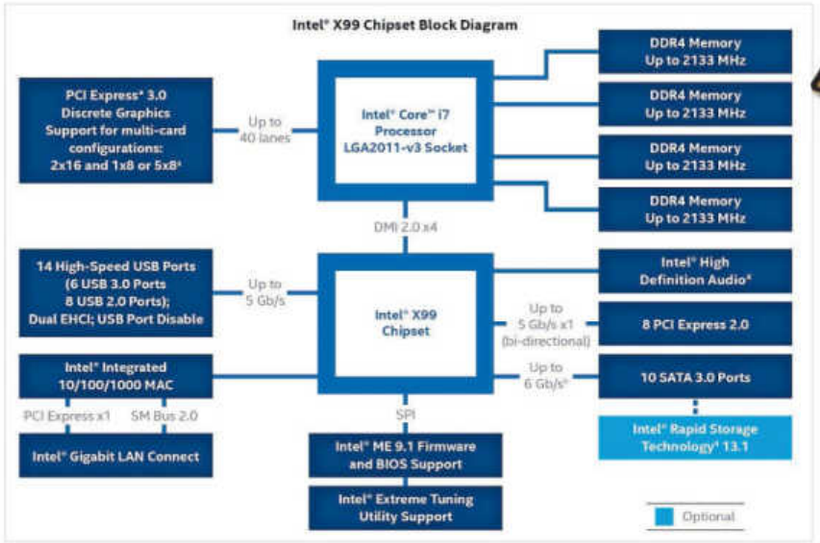
AMD's processors and APUs, meanwhile, use the Piledriver architecture. Its own memory controller was given a speed boost over the previous generation of AMD hardware, but memory support ultimately still isn't as good on this side of the fence. All of AMD's current chips support DDR3 memory, however, some of them are restricted to 1,600MHz or 1,866MHz memory, while only a handful top out at 2,133MHz. Like Intel, these boards do support dual-channel memory.

DON'T FORGET YOUR MOTHER

Processors and chipsets aren't the only bits of your PC kit that need to be checked before shelling out on new memory – motherboards are also vital. You'll need to make sure a board has the right number of slots, and also check what amount and speed of memory it can accept: it's no good dropping a couple of hundred quid on a



Chips using Intel's Haswell-E architecture use the LGA2011 socket and X99 chipset, meaning support for DDR4 is included. That's great news if you do a lot of encoding or rendering, but it won't make a huge difference to gamers.



The X99 chipset introduced DDR4 to the (high-end) mainstream market, bringing with it faster clockspeeds and better power efficiency, but with increased latency.

32GB 3,000MHz kit if your motherboard taps out at 16GB and 2,666MHz.

There are nuances to be examined, then, but for the most part the memory landscape is heartening: no matter what processor, chipset or motherboard you use, you'll be able to equip a rig with plenty of high-end memory at decent speeds. That's good for PC building, but it's not necessarily great news for companies that rely on flogging expensive, high-end kits.

Future developments from Intel and AMD will only improve the situation. Intel's Skylake architecture now supports DDR4 across all of its full-fat desktop chips – but it's also backwards-compatible with DDR3, which adds a huge amount of versatility. We also expect to see future improvements to the memory controller and support for larger amounts of memory running at faster speeds.

AMD isn't standing still, either. Its next proper desktop architecture is called Zen, and it'll offer full DDR4 support to bring the firm's chips alongside Intel.

DDR3 MEMORY: HIT AND MISS

The first set of DDR3 benchmarks we locked and loaded were PC Mark 8's Home, Creative and Work tests – a trio of suites that simulate the kind of low-intensity tasks that take place on many systems, from web browsing and video chatting to word processing and spreadsheets.

Our first tests deployed the bare minimum of sluggish DDR3: 8GB of RAM clocked to 1,333MHz. With this RAM the rig returned scores of 5,170, 6,794 and 5,234 points in the Home, Creative and Work tests – but, with 8GB of 1,600MHz memory deployed, the scores barely improved, with the Creative run only jumping to 6,852.

There wasn't even much of a difference in these tests when we installed 16GB of 1,866MHz memory: in those three benchmarks, the machine scored 5,270, 6,961 and 2,525. The biggest leap came in the Creative test, which suggests more memory helps with photo editing and other trickier tasks, but it's hardly a game-changing jump in performance.

We saw similarly modest gains in other photo-related applications. Gigapan Stitch knits together a group of high-resolution photos, and our test image took 4 minutes and 12 seconds to complete in a rig with 8GB of 1,333MHz memory – but that only improved by 11 seconds when we doubled the RAM and upped its speed to 1,866MHz.

Other application benchmarks saw similarly modest impacts. A Cinebench R15 CPU test with two 4GB, 1,600MHz sticks returned a result of 703; doubling the memory and improving its speed to 1,866MHz only improved that figure to 751.

We only saw big improvements in a few benchmarks when running DDR3 tests. In PC Mark Vantage, our 8GB 1,600MHz rig scored 18,313 points, but doubling the memory and running it at 1,866MHz saw that result jump by almost 3,000 points – a significant increase.

Indeed, our theoretical tests indicate that improving memory amounts and speeds does make a difference, but that these gains don't generally translate to real-world tests.

In SiSoft Sandra's multi-threaded bandwidth test, our 2x 4GB 1,333MHz setup scored 16.57GB/s, but doubling the memory and improving its speed to 1,866MHz saw that result jump to 23.33GB/s. There was a decent jump in single-threaded bandwidth, and cache bandwidth also improved significantly when faster memory was added in larger amounts.

The leap from dual-channel to quad-channel memory doesn't often have much of an impact on our application tests, either. In Cinebench R15's OpenGL test, a machine with two 4GB 1,600MHz sticks scored 111 frames per second, with this score only jumping to 117fps with four 4GB 1,600MHz sticks installed.

When running applications using DDR3, then, the differences between slow and fast memory often aren't huge – and, as long as you've got 8GB of memory installed, then you're going to have enough to get most stuff done in real-world situations.

THE AESTHETICS OF MEMORY

Memory manufacturers try to sell expensive kits on the basis of their size or speed, but that's not the only advantage that comes from shelling out on a high-end set of DIMMs – many of them are designed to look better than cheaper, plain-looking alternatives.

Corsair's Dominator Platinum range sits at the top of the firm's product stack, and some of its key benefits are about the visuals. Corsair boasts of its industrial design and LED lighting – the top metal bar can be upgraded with different attachments, the LEDs can also be changed, plus the box has a good-looking fan kit that can sit on top of the sticks to provide extra cooling.

Expensive memory kits like this don't just have aesthetic advantages – Corsair's Dominator Platinum chips are hand-sorted, have improved monitoring hardware and better heatsinks. But there's no denying the visuals play a part when it comes to high-end memory.

Other firms offer similarly high-end extras. Crucial's Ballistix memory sticks have attractive aluminium heatsinks alongside practical extras like integrated thermal sensors, and Kingston's HyperX Predator and Beast products have good-looking exteriors, but are chosen specifically to provide the best performance.

Kits like this bring practical and visual improvements to the table, then, but they're not always necessary. If you're building a mid-range rig, or want to put together a machine without a window in its case panel, they're simply overkill.

Crucial's Ballistix memory sticks, above, and Kingston's HyperX Beast, below, both boast more than just good looks.

Whether you've got DDR3 or DDR4, upping the size or speed of your memory makes little difference to *Bioshock Infinite*.

There was a noticeable performance difference between our rig with 1,333MHz and 1,600MHz memory installed, but, once beyond that 1,600MHz speed, the gaps between different memory speeds narrowed rapidly. We ran GeekBench's single-core benchmark on 1,600MHz memory, and then again at 2,800MHz memory, but its result only improved by around 100 points.

The benchmarks demonstrate that there are performance gains to be had by installing more memory at faster speeds, but those gains are only noticeable in high-end applications. For most of us, 8GB or 16GB of 1,866MHz memory will be more than enough.

We used Z97 (top) and X99 (bottom) mobos from MSI to carry out our benchmarks.

DDR3 AND GAMING

We tested a variety of games using our DDR3 rig, but only found sporadic improvements. In *Metro: Last Light*, a machine with two 4GB 1,333MHz sticks averaged 126fps, but improving to a pair of 8GB 1,866MHz DIMMs saw that result jump to 144fps.

In both *Bioshock Infinite* and *Batman: Arkham Origins*, though, the improvements were far less impressive – a few frames better in the minimum frame rate benchmark and only a gain of 2fps in the average frame rate result.

There wasn't much of a difference in any of our Unigine Heaven 4.0 tests, either. In all of our DDR3 tests – ranging from a system with two 4GB 1,333MHz sticks to a machine with four 8GB 1,600MHz DIMMs – the benchmark's average frame rate hovered between 63.4fps and 66.8fps. Those configurations didn't differ much in 3D Mark's Fire Strike test either: in the same range of memory setups our results only jumped between 11,607 points and 11,635 points.

THE DDR4 DIFFERENCE

Newer DDR4 memory operates with faster speeds, better channel support and Intel's latest chipset and controller, so we expected our tests to reveal bigger performance disparities.

Our initial tests, though, appeared to follow the blueprint already set out by the older DDR3 sticks. In the Cinebench R15 CPU test, a machine with two 4GB 2,400MHz sticks scored 1,143 points – but doubling the memory and increasing its speed to 3,000MHz only saw that result jump to 1,190 points.

We found similar patterns in the X264 video-encoding test. Our more modest rig ran through its two tests at 205fps and 68fps, but increasing the memory's speed to 3,300MHz saw those results only inch forward to 211fps and 73fps – hardly a jump that'll make a big real-world difference.

Gigapan Stitch's photo-editing tool only saw a couple of seconds' worth of improvement with its memory sped up, and Geekbench exhibited similarly small gains: our first DDR4 rig scored 22,165 points, but doubling the memory to 8GB running at 2,666MHz only saw it jump to 22,849.

It's a shame because, as with DDR3, theoretical tests illustrated that improving speeds and amounts did make a difference. With two 4GB 2,400MHz sticks installed, our test rig delivered 15GB/s and 28.58GB/s of single- and multi-thread bandwidth, with those numbers jumping to 17GB/s and 32GB/s with those same sticks clocked to 3,300MHz.

Those same benchmarks illustrated how DDR4 copes with quad-channel and larger amounts of memory: our machine with two 8GB sticks may have delivered 32GB/s of multi-threaded bandwidth, but doubling the memory saw that figure leap to 45GB/s.

Quad-channel delivered impressive numbers throughout our benchmarks, then, but those figures weren't always translated to real-world tests – so we'd say that

The Batman is unimpressed by the speed of your memory.

Metro: Last Light **was our only DDR3 gaming test to noticeably improve with more memory.**

it's not a vital addition to your PC unless you're keen on buying a Haswell-E system to run intensive work applications or the most demanding games.

DDR4 AND GAMING

We saw a big jump in just one of our gaming benchmarks, *Metro: Last Light*, while testing with DDR3. However, updated DDR4 memory proved even less dramatic. Improving the amount and speed of memory saw our *Metro: Last Light* results jump by a mere couple of frames, and our biggest improvements in *Bioshock Infinite* and *Batman* also only saw increases of a frame or two, no matter the amount or speed of DDR4.

We'll let Unigine Heaven have the last word. Our rig averaged 62.7fps with two 4GB 2,400MHz sticks installed, but this only improved to 64.2fps once we installed four 8GB 2,666MHz DIMMs.

There's no doubt about the pure, naked speed of DDR4, but it looks like we're at the point, for gaming, especially, where any 8GB dual- or quad-channel configuration will be ample. Memory simply isn't the bottleneck in gaming. Processors and graphics cards are the components that are more likely to be holding back your frame rates.

WHAT MEMORY DO YOU REALLY NEED?

It's tempting to buy the fastest and largest memory kit you can afford when putting together a new build, but, as many of our benchmarks illustrate, aiming for the top of the tech tree is actually an unnecessary extravagance when it comes to memory.

The story is the same whether you're creating a PC to use DDR3 or DDR4. A decent amount like 8GB or 16GB running at a reasonable speed will be enough to handle most tasks you throw its way, whether it's for work or gaming.

You'll still see benefits if you buy larger and faster kits, sure, but they'll be less significant – so it's only worth looking towards these kits if you're a true enthusiast who wants the best parts available or if you're running unusually demanding software and need to wring every bit of performance from your PC.

Quad-channel kits, meanwhile, are great if you're using applications that'll truly take advantage of DDR4's improved architecture, like encoding or rendering – but most people won't feel the benefit. It's no surprise, then, that it's only available with expensive X99-based CPUs.

Most people just don't need to shell out for the priciest kits around, and that's definitely no bad thing. Memory, processor and chipset development has levelled the playing field, which means it's one less component to worry about when putting together a new PC.

"Once beyond that 1,600MHz speed, the gaps between different memory speeds narrowed rapidly."

PENTIUMS, CELERONS AND APUs: BUYING MEMORY FOR A BUDGET PC

Our tests have examined the effect of different memory on high-end machines, but if you're building a budget rig, then different considerations should come to the fore at checkout time.

For starters, don't shell out on an expensive, fast memory kit if you're going to be constructing a PC built around one of Intel's Haswell-based Celeron or Pentium chips, as most of these only support DDR3 that runs at 1,333MHz. That's slow enough to cause a performance hit in many benchmarks, but on a low-end rig, it's unlikely you'll be running the sorts of applications that'll suffer with lesser speeds.

AMD's APUs are more accepting to faster memory, but you'll still need to pay attention to speeds. A couple of its cheapest parts only handle 1,333MHz or 1,600MHz DDR3, but most can support 1,866MHz sticks. It's the same on the CPU side, with FX chips mostly supporting 1,866MHz parts.

There's one other main consideration when putting together a budget machine: the motherboard. Budget boards don't often support the extreme speeds offered by pricier components, and many – especially at smaller form-factors – only have two slots, rather than four. That's fine if you're building a system you don't intend to upgrade, but it can prove restrictive if you want to add more memory later.

Don't bother with high-end memory if you're running an A10-7850K or Pentium K.

ANATOMY OF A MONITOR

GET THE FULL PICTURE ON WHAT'S INSIDE YOUR SCREEN

✓ Types of LCD

Virtually all monitors are built with LCD screens, but different types of panel within this category can deliver different experiences and cater for different budgets.

The most prevalent is IPS. This used to be one of the most expensive, but prices have dropped and these panels sit comfortably in the mid-range as well as the high end now. They've got superb viewing angles and excel when it comes to colour accuracy, but their response times can be mediocre. That makes them great for work and general use – especially if you're going to do photo editing – but poor for high-octane gaming.

TN panels are also popular. They've got lightning fast response times, which makes them tempting for pro-level gamers, but it comes at a cost – viewing angles and colour accuracy both suffer, and their black levels often aren't as good as those on IPS. Screens with TN technology are cheaper, though.

The third panel category, VA, is less popular. These screens correct the issues found on TN panels, but black levels are poor, and response times also disappoint.

✓ Backlighting

The LCD monitors that most of us buy use LED backlights, but there are different types of hardware to consider in this category, too.

The backlights used today are divided into two categories. The first, WLED, is the most common – and the most affordable. It works by illuminating the screen using white LEDs lined around the edge of the screen, with a diffuser deployed to spread light across the panel. They're good for brightness, but less impressive when it comes to delivering bright, vivid colours.

The other option is RGB LED, which is rarer and much dearer. The LEDs are spread across the entire panel, and each LED can produce red, blue and green light; a big improvement on the white LEDs of cheaper screens. That means there's a huge amount of versatility on the screens, which can use their multi-coloured talents to display a much wider colour gamut.

✓ Resolution and aspect ratio

Resolution determines how many pixels you've got to play with. Too few and you'll have a cramped screen that's tricky to use for work or play; too many and they could be wasted if you don't make use of them, or you might need new graphics card to keep up.

The most popular desktop resolution now 1,920 x 1,080, but others are becoming more prominent. The next step up is 2,440 x 1,440, which is enjoyed by gamers searching for a little more clarity. Beyond that there's 4K – screens with a mighty 3,480 x 2,160 resolution – and widescreen models that boast 3,440 x 1,440 resolutions.

That latter screen has a 21:9 aspect ratio. That's another feature that needs consideration before you make a purchase; a wider screen is good for watching films, but its letterbox effect could prove irritating if you're using it for office work. Most screens sold today use the 16:9 aspect ratio. That's wider than the 4:3 ratio that was popular on CRT monitors, but still tall enough to work in most scenarios.

✓ Connections

Monitors often come with a multitude of different ports and connections. Three main types of port usually found on screens are HDMI, DVI and DisplayPort.

The former two are more common, but the latter is newer – it's usually used to power panels with extremely high resolutions. It's vital to check that the ports on a new screen match the outputs on your PC or graphics card – if they don't, you'll have to buy an adaptor.

That's not the only connectivity option found on many screens. Some include USB ports – a separate USB connection will make them work by connecting to a USB port on the PC itself – and others include card readers as well.

Multimedia screens often include speakers, too, so sometimes they have a 3.5mm audio jack. Again, it needs to be connected to an audio output on the PC to function.

"THE JUMP BETWEEN 120HZ AND 240HZ WILL BE MINOR, AND YOU'LL NEED A MIGHTY GRAPHICS CARD"

✓ Refresh rates

This term represents the number of times in a second that a display is refreshed. We've got used to displays that use a 60Hz refresh rate, but recent developments have seen 120Hz monitors become more prevalent.

Screens with 60Hz refresh rates can display 60fps, which is fine for almost everyone – but keen gamers will enjoy 120Hz screens, because these panels can run at 120fps. If you've got a graphics card that can handle it, such a panel would make fast, frantic gameplay seem even smoother, with a lower chance of blurring or screen tearing.

The first 240Hz screens have begun to appear, too, although some of these screens merely convert 120Hz signals rather than run at a native 240Hz. The jump between 120Hz and 240Hz will be minor, though, and you'll need a mighty graphics card to generate all of those frames.

✓ The stand

Much of a screen's versatility and strength actually comes from its stand. This is one area where cheaper monitors tend to lag behind pricier competition – their stands often have very little in the way of adjustment options.

A good monitor's stand will be able to tilt the screen back and forward, and also move left to right. The best screens also have a swivelling mechanism that allows the panel to be rotated between portrait and landscape orientations.

High-quality stands don't just move in all directions – they show off great build quality, too. The best units are made from metal, and their sturdy bases look really good as well as inspire confidence. Cheaper stands are usually made from a flimsier plastic construction.

Some screens are also compatible with VESA mounts, which are handy. This system is found on the back of screens or stands, and is used to connect the screen to wall-mounting mechanisms. ■

FLAT-PANEL PERFECTION

With more features and technology than ever, welcome to the golden age of PC monitors!

A FEW YEARS AGO, the market for monitors was as exciting as binge-watching The Best Of The House Of Lords. Maybe not quite that bad, but your choices basically boiled down to a couple of resolutions across a few screen sizes. There was the TN versus IPS thing when it came to panel technology, too, with VA thrown in as a wild card. And the introduction of LED backlights shook things up a bit. But the fires of innovation were hardly burning bright.

Fast-forward to today, and you've got the opposite problem. There's so much choice, it's hard to know where to start. Size-wise, you can go all the way to 40 inches without even spending all that much cash. Resolutions up to full 4K are now affordable, too. And you can now snag something with a super-wide aspect ratio. Oh, and don't forget to decide if you want a flat or curved panel. You also need to decide whether high refresh rates of 120Hz and more are your bag. And do you want that with or without Nvidia's G-Sync adaptive sync technology? Or AMD's alternative? You might want to bear in mind flicker-free backlight technology, too.

Meanwhile, if we still seem to be stuck with the same choice of core LCD panel technologies as before—with TN, IPS, and VA—recent developments have blurred the boundaries. TN technology is not the image-quality dud it used to be.

And as if all that isn't enough, the near future will bring further complications. How about more vibrant colours, and the best ever contrast from an LCD monitor, thanks to quantum dot technology? However you slice it, there's much, much more to keep up with than before. So let's take a quick look about the tech that's most important, and help you make the right decision about your newest window into the computing world.

WITH SO MANY different screen types, sizes, and technologies on offer, it's difficult to know where to begin. So let's start with something familiar. Do you want a TN, IPS, or VA LCD panel in your monitor?

Much will come down to your preferred usage. TN remains the fastest and most responsive technology, so that's great for games. IPS is still the best for colour accuracy, both in static terms and in terms of maintaining accuracy from different viewing angles. That makes IPS great for serious applications, such as image-editing, and also for general Windows work. VA, meanwhile, has a pretty good line in contrast and colour vibrancy. An obvious pick for watching lots of video and movies, then.

Where things get more complicated involves the increasing convergence of panel quality, regardless of type. As each panel type improves, they all inevitably converge on the same high-quality image production. True perfection hasn't been achieved, of course. And in many ways, LCD panels powered by backlights are fundamentally flawed compared to likely future display technologies, which produce light on a per-pixel basis. But as an example, some of the very latest TN panels have far better colours and contrast than before, and in those regards now rival cheaper IPS panels, at the same time as maintaining their speed and response advantage.

Meanwhile, some of the other technologies out there don't always play nicely with every panel type. If you want high refresh in an IPS panel, for instance, you limit your choice to a tiny handful of panels. If you want high refresh, IPS, and 4K, you're out of luck. You can't currently buy a PC monitor that combines all three. So that's an important early lesson. As things currently stand, you can't necessarily cherry-pick your favorite features and expect there to be a monitor that delivers them all. Some combinations simply don't exist.

THE NUMBERS GAME

Next, let's talk native resolution. Specifically, the question of whether more pixels are always better. The 3,840 by 2,160 pixel grid of the latest 4K monitors certainly gives you more working space for apps, and more detail in games. But there are catches.

For starters, even Windows 10's interface doesn't scale flawlessly if you change the DPI setting away from 100 percent. That means smaller screens with very high resolutions can be problematic. The current crop of cheap 28-inch 4K monitors are as small as we think most people should go; 32-inch and up works better because it means you can use the screen comfortably without scaling. For gamers, 4K is a problem, too, because it makes for one heck of a load on your graphics card. Later in 2016, we're expecting new GPUs that can handle 4K gaming with relative ease. For now, it's a potential stumbling point, especially if your graphics card has a year or two under its belt.

A similar problem applies to very high refresh monitors, especially those that also offer high resolutions. Driving a 2560x1440 at 60fps at very high detail is hardly a gimme, but if you want to make

Nvidia's G-Sync is currently the pick of the adaptive sync options.

> "As each panel type improves, they all inevitably converge on the same high-quality image production.

Below: Say "Hello" to 34 inches of curved LCD hotness, courtesy of Acer.

Right: Philips' 4K 40-inch übertron is surprisingly affordable.

the most of a 144Hz panel, you'll need over double that frame rate from your graphics card. Ouch!

On the other hand, once you've experienced the slick smoothness of a high-refresh monitor, you may be hooked. Moreover, if you're not a big gamer, the load on your GPU is less of an issue. And yet your choice is still limited. Want a 40-inch 4K monitor with at least 120Hz support? You're out of luck.

GOING WIDE

Next up is the new crop of superwide screens with 21:9 aspect ratios. The latest take on this format is a group of 34-inch monitors with 3,440 by 1,440 pixels. For games and 21:9 aspect movies, these are spectacular. In many ways, they're the gamer's choice right now. Except you can't have them with high refresh, nor with the fastest panel tech. Tricky.

For everything apart from games, that 21:9 aspect is a problem. With standard 16:9 aspect HDTV content, you're left with big black bars on either side of the screen. And on the Windows desktop, similar money will buy you a 40-inch 4K screen with far, far more real estate, especially when it comes to vertical resolution. It's a similar situation with curved 21:9 monitors. Awesome for games, suspect as general-purpose panels.

Another technology that you can rule in or out based on the whole gamer or not-gamer thing is adaptive sync. For gamers, the ability to synchronize the fluctuating frame rate of your graphics card, in-game, with the refresh of your monitor is a really big deal.

If you are a gamer, you'll need to choose between Nvidia's G-Sync and AMD's FreeSync technology, of course. But, for now, that's not much of a choice. G-Sync is a finished and polished product. FreeSync is much more a work in progress. Nvidia wins that one hands down right now.

If those are the key tech options, you then have to mix and match them according to your preferences. Do you want 4K TN at an affordable 28 inches? Or how about 21:9 aspect, 34-inch, a curved screen, and adaptive syncing? Of course, that may be a bit rich, and you don't play games, so an affordable 27-inch, with a nice 2560x1440 IPS panel might be your bag. Then again, maybe you're a purist gamer who demands ultra-fast responses and high refresh rates. Or you might be on a really tight budget, so a modest 22-inch 1080p is nearer your price point.

It's confusing stuff, but while it's true that you can't quite have any combination of the latest technologies and features in a single screen, there's a very good chance there's something out that's awfully close to your perfect panel. Just bear your own requirements in mind, and – whatever you do – don't go for the cheap option if you can help it.

Right: Even with Nvidia's mighty GeForce 980Ti, driving 4K displays is a big ask.

Below: Asus's upcoming RoG PG34Q promises to be a gamer's delight.

QUANTUM LEAP

The last few years have seen innovation on an awesome scale. So, are we done, or can you expect more of the same in 2016? One thing is for sure: More pixels are likely to be on the 2016 menu. A few 5K screens have already popped up. Could 8K be the big thing in 2016? Maybe. LG and other makers of LCD panels are currently tooling up for 8K—that means 7,680 by 4,320 pixels, or no fewer than a grand total of 33,177,600 dots. Or if you count each RGB sub-pixel, we're talking 99,532,800 coloured dots being refreshed at least 60 times a second.

More likely to see wider mainstream adoption is quantum dot technology. Already popular in the HDTV market, it's not revolutionary—it's about making LCD panels even better. In fact, you don't even need a new LCD panel for quantum dot to do its stuff. Just a new backlight. So, what is it?

If you didn't major in physics, this could be tricky, because here we enter the realm of nanomaterials. In this case, it's a material that absorbs certain frequencies of light, converts it, and re-emits. The "quantum" bit is because the semiconductor crystal material leverages a nanoscale effect known as quantum confinement, which involves electron holes, the exciton Bohr radius, and two-dimensional potential wells. You knew that, right?

The point is that these dots are highly tunable. So you can take something like a cheap, dirty LED backlight, and use this material to clean up the light. So you can use quantum dot tech to greatly improve the quality of a cheap, single-colour LED backlight, and make it as good as or better than an expensive RGB backlight. That means more accurate and vivid colours without the big bills.

Philips was first out of the box with a quantum dot PC display in 2015. The technology really works and makes screens visibly more vivid. We're expecting a significant roll-out of QD in 2016.

Everyth

The first rule of thermodynamics is: you do not talk about thermodynamics*. The second rule of thermodynamics is: if you have a hardware problem, there's a good chance heat is to blame. Heat is the nemesis of pretty much everything you're trying to do with your system. Want to run your processor faster? Heat is holding you back. Speed up graphics? Heat will happily shut that door in your face. Pack more juicy components into your chassis? You'd better allow for good airflow or the whole lot will be brought to its knees gasping for air.

The ways we tackle heat production has evolved over the years. Original PCs didn't go in for all this active cooling malachy. Indeed it wasn't too long ago (in human evolution terms at least) that your CPU would've needed to be something special to boast even a heatsink. As time has passed though, and processor designs developed, more aggressive cooling has been needed. And despite a few blips along the way, we now find ourselves at a point where an aftermarket cooler is pretty much expected – especially if you're looking to get the most from your processor.

We're not just talking about overclocking when we say that either, because as CPU designs have developed, so effective heat management has become essential. This in turn means that part of the silicon in the latest CPUs is there to monitor just how hot the chip is getting, and thus it can control the speed at which it is operating. This is the basis of Intel's Turbo mode. The Core i7-4770k for instance may have a base frequency of 3.5GHz, but if the chip is cool enough it can up the frequency to 3.9GHz on the fly. The trick therefore is to make sure it has that headroom available, and one of the best ways of doing that is to toss out the basic CPU cooler that came with your chip and replace it with a closed-loop water cooler.

* NOTE: These rules should not be confused with the laws of thermodynamics, which are far scarier and essentially state that chaos will ultimately win.

ing's Cool

Understand your PC's thermodynamics to unlock its true power

Check out the specs sheets of your CPU, and you'll find reference to its TDP. Standing for thermal design power, it's an indication of how much heat a component produces when used. It may not be immediately obvious what the TDP is actually referring to, but it's not the peak wattage you can expect a given chip to run at. In fact, it's defined as the average power dissipation when running at the base frequency. So not at the turbo frequency even.

Rather than being the peak thermal power you need to allow for in a worst case scenario, the TDP of a processor is actually the thermal point that you're likely to see in normal day-to-day usage. This is a reason why TDP is sometimes referred to as the thermal design point. To give an example, the TDP for the Core i7-4770K is 85W, so in order to keep the chip running optimally, the chip's cooler has to be capable of shifting at least 85W of energy.

That this isn't the peak heat output is important – you can work out the thermodynamics of your system to a wonderful degree, only for the chip to overheat and bring your system to its knees when really thrashing it. Overcompensating on your cooling means your CPU won't be throttled, which in turn means you'll be getting the very best from it. Or, put another way, getting what you paid for. And the best way of overcompensating is to water cool your chip.

Water cooling has been held up as the pinnacle of cooling by the modding fraternity for years, but for many the hassle of setting up such a system outweighs the benefits. It's simply too much trouble for the vast majority, with the added fear of throwing water all over your motherboard. This is where closed-loop solutions ease into view and offer most of the benefits of a full water-cooling system, but in a much easier-to-swallow form.

Compare the cooling afforded by a closed-loop water cooler with a decent air cooler and you'd be forgiven for thinking there wasn't a lot in it. Simply look at the operating temperatures at full load and then the differences can indeed be slight. However, that isn't the whole story. An important factor in these days of turbo mode is the time it takes to go from the high temperatures of full-load down to the idle temperature, and it's here that closed-loop water coolers really come into their own – as generally they'll drop back down to idle levels in seconds rather than minutes. And that means the CPU can turbo much sooner once again.

ABOVE LEFT:
No need to worry about drowning your Z97 with a closed-loop system.

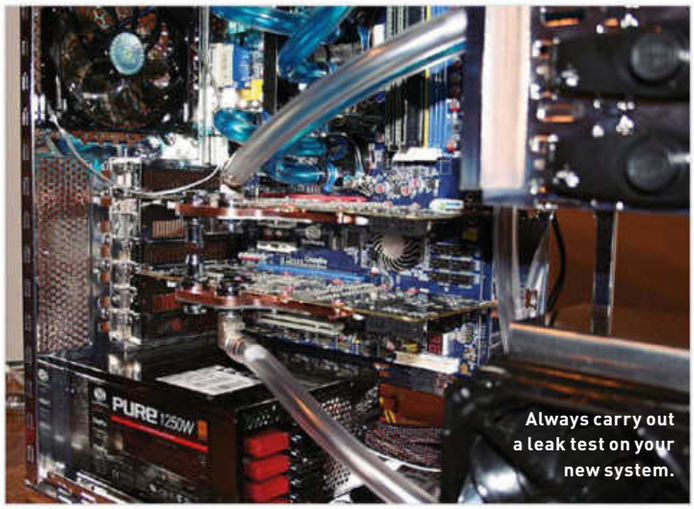
ABOVE RIGHT:
If space is an issue for you, try a 120mm cooler.

COOL WATER

In a standard water-cooling system you have one or more water blocks in contact with the components you wish to cool. A flow of water is maintained through these blocks and the radiator that cools the water down again through the use of a water pump. In order to improve the efficiency of the radiator, one or two fans are used, while a reservoir is

Your cooler size is largely dependent on your case size.

It's vital your system has good contact with your processer.



Always carry out a leak test on your new system.

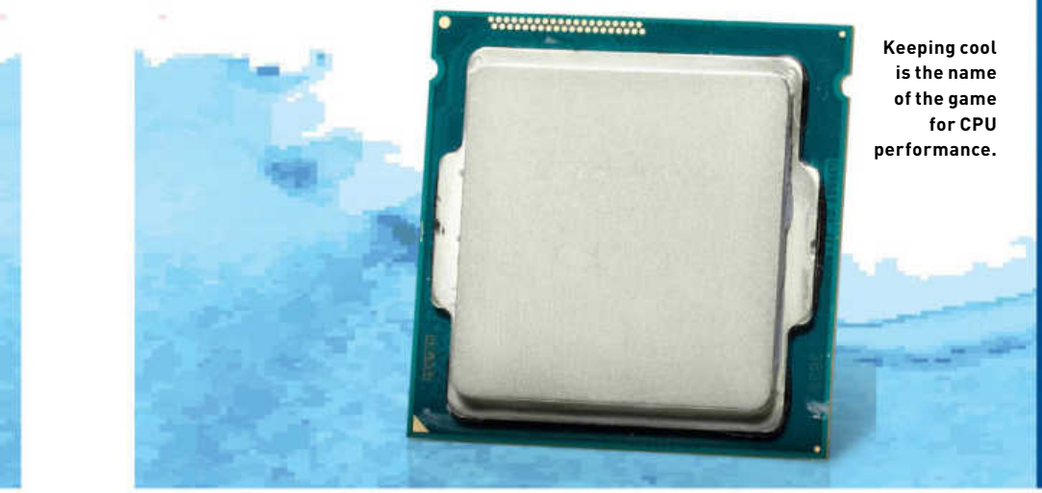
also present to ensure that there's enough liquid in the system to keep things running smoothly.

All these elements are present in closed-loop systems too. The reservoir is often combined into the water block, while the water pump either sits in the radiator or in some cases on top of the water block. The specifics differ between products, with the number of fans ranging from one 120mm cooler all the way up to three fan systems. Two fan systems are quickly becoming the norm though, either on a 120mm-long radiator with a fan on each side, or a 240mm radiator with the fans next to each other. Which one you go for is largely determined by how much money you have available to spend on cooling and how much room you have in your case.

One thing to consider when making the move to a closed-loop water cooler is that it moves the main heat pump away from the centre of your rig. Depending on the air cooler that you're replacing and the layout of your case, this can either be a good or bad thing. It may mean that you have to add extra system cooling to ensure there's still a good airflow over your motherboard, and specifically over the power regulators that are behind the ATX connectors. Good airflow is also a good idea for your system storage of course. Going down the closed-loop water cooling route isn't going to solve all of your system-cooling needs with one unit, in other words.

Closed-loop systems are gaining traction in other areas though. You only have to look at AMD's R9 295X2 cards to see that closed-loop solutions aren't limited to just sorting out the heat generated by your processor. Indeed traditionally, water cooling configurations would often include water cooling for your graphics card, processor and in some cases the power circuitry of your motherboard as well.

And there's nothing to stop you going down the full system cooling route even today, of course. The choice, really, is up to you; we're partial to a closed-loop system, but we're not going to force you or anything. You do what you like. ■

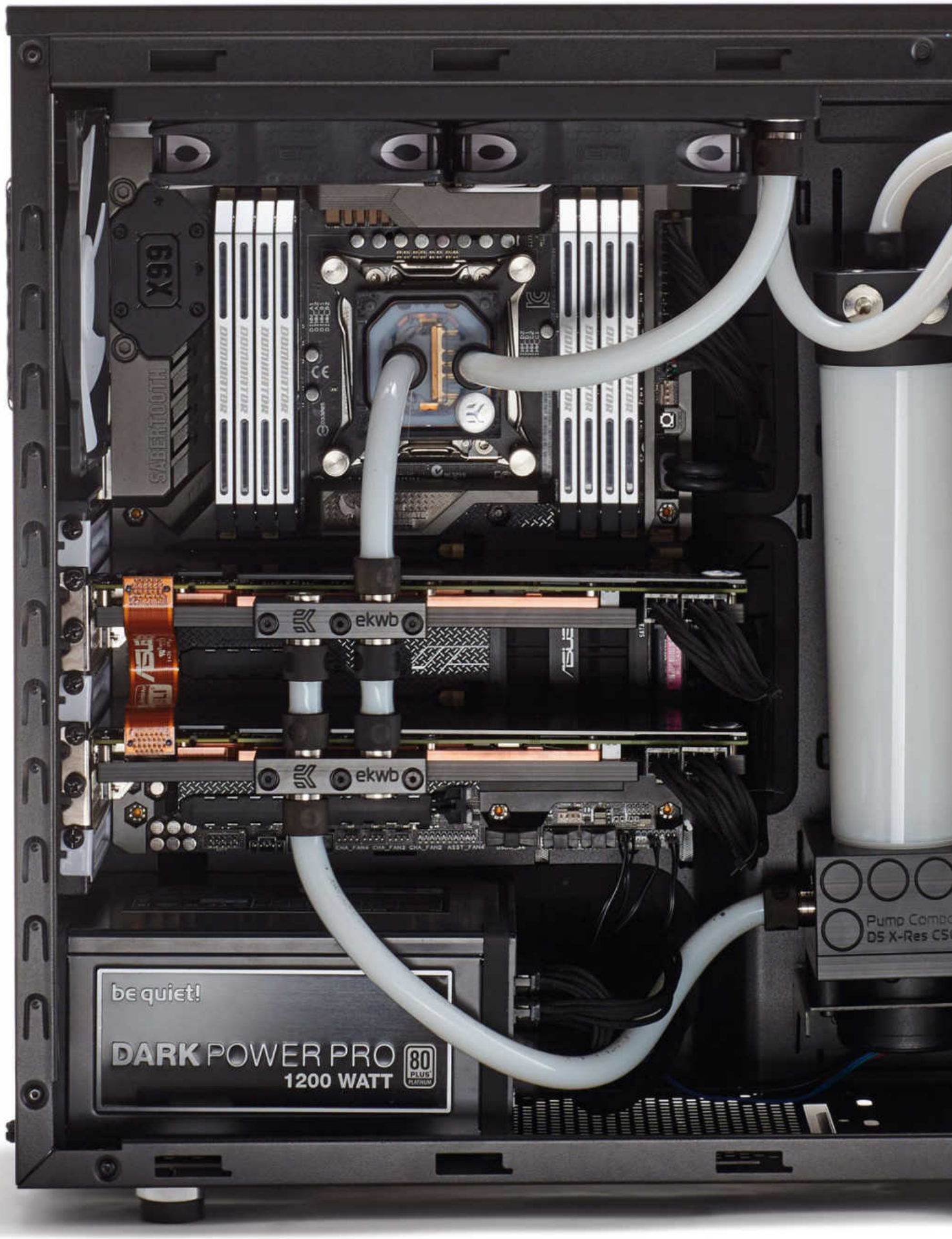

Keeping cool is the name of the game for CPU performance.

INSTALLATION FUN AND GAMES

Installing CPU coolers is, we're pretty sure, one of the circles of Hell described in *Dante's Inferno* – as a chore to be carried out by telephone conmen who talk the elderly into installing viruses onto their PCs. Either way it can be a real pain. Often literally. Most closed-loop coolers are every bit as tricky as awkward air coolers on this front – the good ones use easily accessible clips and thumb screws, while the worst offenders have you stripping the skin off your fingers to actually attach the main block on top of your precious CPU. Removing your motherboard from the case is often a requirement, even if said chassis has a cutout on the motherboard mounting. Accept that you're going to have to do this and get on with it is our only advice.

There is an added complication with closed-loop water coolers though, and that's the huge fan/heatsink combo you need to trail through your system and somehow attach to your case. If you've spent a good chunk of cash on your chassis then this may not be too much of a problem – but still check the measurements of the cooling array to make sure you have enough room; particularly if you're going for a 240mm, double-fan cooler. Even single-fan radiators can be tricky though, due to the thickness of the fan and radiator combined.

Again, make sure you've got enough room in your case before you buy one. Such coolers are usually installed in the top of the case, although single-fan 120mm can sometime squeeze in above the CPU socket on the rear. Make sure the water pipes aren't twisted between the CPU and the radiator, and don't forget to attach the pump power cables either – forgetting this is a great way of seeing just how quickly your CPU can hit maximum temperature, but it's rubbish for getting the most out of your CPU.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ekwb
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DARK POWER PRO
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80 PLUS PLATINUM

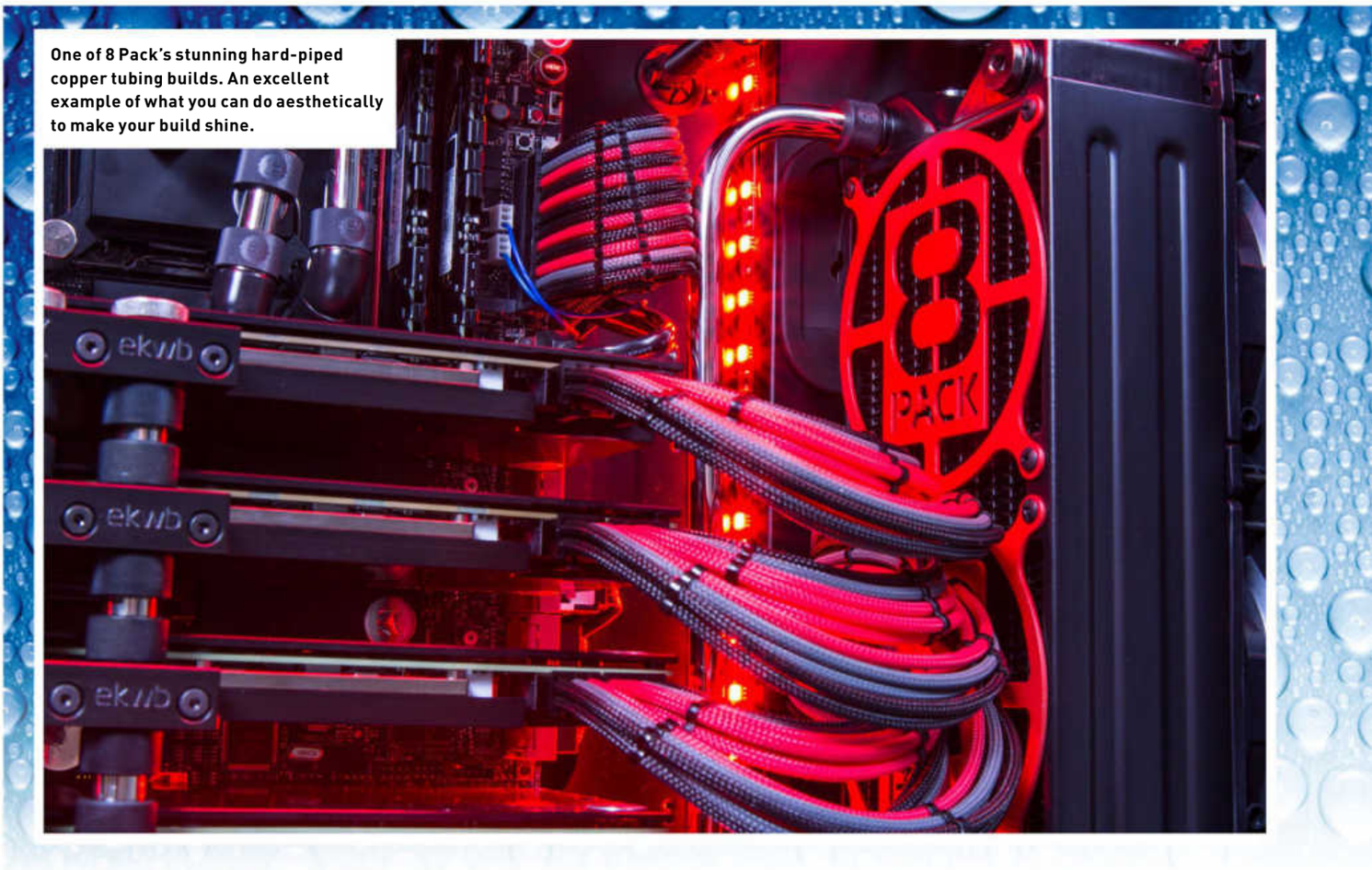
WATER COOLING 101

What strokes do you need to learn to become a water-cooling master?

For much of recent history, water cooling has been shunned. Only a select few could afford to merrily dance with computing death, taking their chances with water-cooling hardware and components that weren't even designed to work in the silicon environment. They'd ghetto-graft 1/4-inch plumbing fittings onto hardware and hand-mill various water blocks, all in the hope of creating a leak-proof, watertight system. A system that could efficiently and effectively transfer heat away from their component parts, to a far greater degree than traditional air coolers ever could.

It was back in the noughties, a time when the average PC enthusiast was less concerned about how a PC looked. More important was how many frames per second they could squeeze from their beige box of dominance in *Unreal Tournament*. It was a terrifying time. But over the last five years, the situation has changed dramatically.

Water-cooling manufacturers and modding companies – such as EKWB, XSPC, Primochill, Bitspower and E22 – have come to the forefront in far greater numbers. This is when and why water cooling really began to take centre stage. Indeed, today you'd be hard-pressed to find a high-end system that's not running some form of all-in-one CPU cooler or a custom loop. Hell, all of us here at Future Towers would be running hard-piped builds if we could, and there isn't one of us still stuck on the retail cooler, or even an air cooler for that matter.



One of 8 Pack's stunning hard-piped copper tubing builds. An excellent example of what you can do aesthetically to make your build shine.

So, what is it that attracts people to water cooling? Why is it so much better than traditional air cooling? Essentially, all forms of cooling work on the same basic principles. You might have heard of them, they're part of the laws of thermal and fluid dynamics. No matter whether you have an air cooler or a full custom-loop setup, you're transferring heat using water from one point to the other. It then cools and circulates back around again to transfer that heat out of the system and to the outside environment again and again.

All very fancy, right? Air cooling technically isn't an accurate description of that cooling method, and neither is water cooling – they both essentially require a fan and a radiator to exhaust that heat. So, is water cooling for you? Should you dive into the murky depths of H_2O nirvana? Maybe you'll discover something about yourself along the way... Read on to find out.

WHY WATER COOL?

Let's cut straight to it. Primarily, water cooling is done to enhance the aesthetic beauty of a build. Don't get us wrong, the heat-reducing properties of multiple radiators and fans cooling your internal components is fantastic and highly efficient. But if you're looking for the most effective price-to-performance ratios, a good AIO cooler for your CPU and a triple fan-designed GPU would be more than enough to ensure you never hit any of the thermal limits dictated to us by our silicon-inducing overlords. And in today's technological climate, you're far more likely to encounter hardware-based limits, rather than temperature-based ones, in your overclock attempts.

One of the biggest benefits of water cooling, besides looking better than Gabe Newell's monthly bank statements, is the noise reduction. Simply put, noise control is all about effective fan control. It's not necessarily how many fans you have, but how fast they're spinning. Ultimately, the lower the RPM, the lower the noise output. For instance, if you take five 120mm fans and run them at 1,200rpm, and then take two separate 120mm fans and run them at 3,000rpm, we can guarantee the two fans will be creating more audible noise than the five.

"One of the benefits of water cooling is noise reduction."

AESTHETICS

Water cooling is primarily about enhancing the look of your build, ensuring your silicon shrapnel stands out from the crowd and looks as good as it possibly can. There are multiple ways of doing this with water cooling. By all means, we're not saying that air-cooled builds can't look good – there are some seriously stunning rigs out there that run on simple old air coolers. But water cooling sits at the centre of the modding community. It's responsible for most of the innovations we've seen in this area of the market. Whether that's braided cables, windowed-side panels or LED lighting, you can assume that the vast majority of these ideas originated from some modder out there ghettoing an idea onto one of their builds, and then showing it off to the masses.

So, you have four options in total when it comes to liquefying your machine. First, you could simply just use an AIO cooler. This way, you avoid the hassle of setting up any kind of crazy system, you're covered by a warranty and still gain the benefits of having a water-cooled CPU. Your second option is to go with a soft tubing loop, utilising flexible coloured or clear tubing. This is one of the most adaptable water-cooling methods as the tubing is flexible and easy to use.

The third and currently most popular option is to use acrylic tubing, most notably PETG tubing. This non-fragile, highly robust hard piping creates an entirely different look for a build, utilising

EK's Supremacy Evo CPU block provides incredible cooling with a simple mounting mechanism. We went transparent to show off our snazzy white pastel coolant.

straight lines and angles to really make your rig pop. And then, finally, there's copper tubing. It's identical in almost every way to acrylic tubing, except it's far easier to bend and a lot cheaper, too. Copper provides a good base to either nickel or chrome plate or even powder coat as well, though it's opaque. Whichever way you choose, you'll still benefit from the reduced noise and the far-superior cooling capacity that water cooling provides.

WATER-COOLING COMPONENTS

If you thought that building a custom PC was tricky enough, then we've got some bad news for you. Here's a quick rundown of what you'll have to consider purchasing on top of your standard build. You'll need: A case, tubing, radiator(s), a CPU block, GPU block(s), GPU backplate(s), memory block(s), reservoir(s), pump(s), compression fittings, angled fittings, bulkhead fittings, stop valves, coolant and fans. Once you've decided how you want to cool your rig and what chassis you want to cool your build in, then it's a simple matter of pricing the lot up, throwing it all in the basket and breaking your wallet in two as you fork out for an expensive exercise in PC modding.

CPU BLOCK

By far the most obvious component to cool your rig. You'll need to make sure you buy a CPU block that's compatible with the chip you're trying to cool. More often than not, this is just a simple difference between Intel and AMD, as the processors don't tend to vary greatly in size.

GPU BLOCK

Predictably, GPUs experience the greatest deal of variance. Both in the design of the PCB and in which graphics processor you choose as well. You'll need to make sure you buy a compatible block for your card. Some manufacturers, such as EKWB, will often include specific water blocks designed to work with aftermarket cards such as Gigabyte's Windforce, MSI's Lightning or the Asus STRIX series of cards. This may extend as far as the backplate as well, so always double check.

DISPELLING THE MYTHS

MANY FICTIONS CLOUD THE WORLD OF WATER COOLING, SO WE'VE SIFTED THE REALITY FROM THE RUMOUR

MYTH 1

If I use deionised water in my loop, then leaks won't matter or cause any damage.

Answer Unfortunately, no. As soon as the water is introduced to the system, it will begin making contact with the various metals inside of the water blocks. It will soon be picking up positive ions, meaning it'll be conductive within a couple of hours, at the very least.

MYTH 2

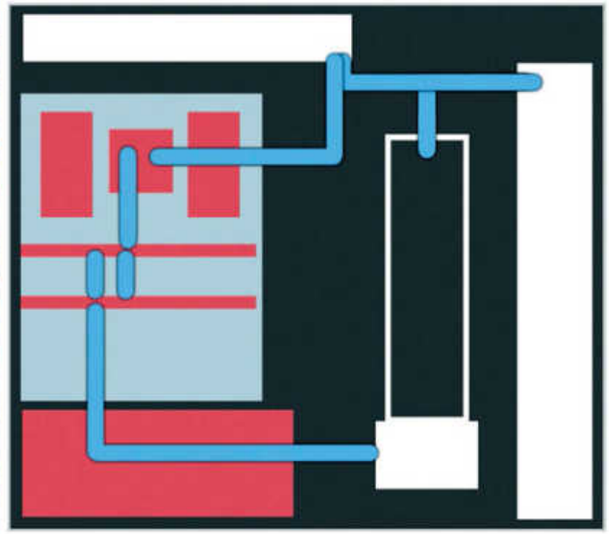
What If I blow it up when I switch it on? What if there's an instant leak?

Answer Honestly, you're seriously not going to damage anything. The best way to fill and test a loop is to make sure everything's unpowered by using a PSU bridge. By using this bridge, you can switch on just the pump and that's it. Leave this on for 24–48 hours to see if you have any leaks.

MYTH 3

If I water cool my PC and add more fans, it's going to cool down my room right?

Answer Definitely not. In fact, it's more than likely that the opposite will occur. Your hardware may run cooler, but you'll still be outputting the same amount of heat (or maybe even more if you're ramping up that overclock higher), out of the same radiators. If anything, your room will become warmer as you'll have more fans pushing more heat out of those radiators.



Even if it's just a shoddy Photoshop design, planning your build visually will save you time when it comes to figuring out how many fittings you're going to need and how best to run your cooling loops.

Making sure you've got enough space to work inside of your chassis is vital for having a stress-free, easy build.

MEMORY BLOCK

Whether or not you decide to cool the RAM with your custom loop is entirely up to you. They certainly do output heat. But really, it just looks more awesome than anything else. Besides, nobody will penalise you if all you're looking for is to cool your CPU and GPU. You'll also need compatible RAM modules that match up with your water blocks.

FITTINGS

The most important parts of your build are the fittings you choose to use. Depending on what tubing you decide upon, you'll need either compression fittings or acrylic fittings. Although acrylic fittings are still technically compression fittings, they're designed to work around hard tubing by not crushing the acrylic as much, unlike traditional compression fittings, which tend to have a greater pinch to them. If you're looking for a basic build, you can usually get away with just the standard fittings.

However, if you're looking at designing a build with cleaner lines and a little more flare, you may want to invest in some angled fittings as well, usually stipulated at 45 or 90 degrees. Additionally, a stop valve might come in handy for loop maintenance.

PUMP / RESERVOIRS

Technically, you don't need to buy a reservoir to successfully run a water-cooled loop. However, they do look rather impressive, and make it a lot easier to fill a water-cooled system than using other methods. You will, however, always need a pump to ensure that the fluid within your system is flowing, and pulling heat away from your core components and out to the radiators. Additionally, you should always have your pump gravity fed (meaning fluid should always be flowing down into it).

RADIATORS AND STATIC PRESSURE

At this point, you need to be looking at how you're going to output that heat. The only option you have is to use radiators. You can do this however you like, either by utilising separate loops for your GPUs and CPUs or by combining the two together into one single loop. But you'll still need radiators to get rid of all of that heat, and accompanying fans to reduce this per loop.

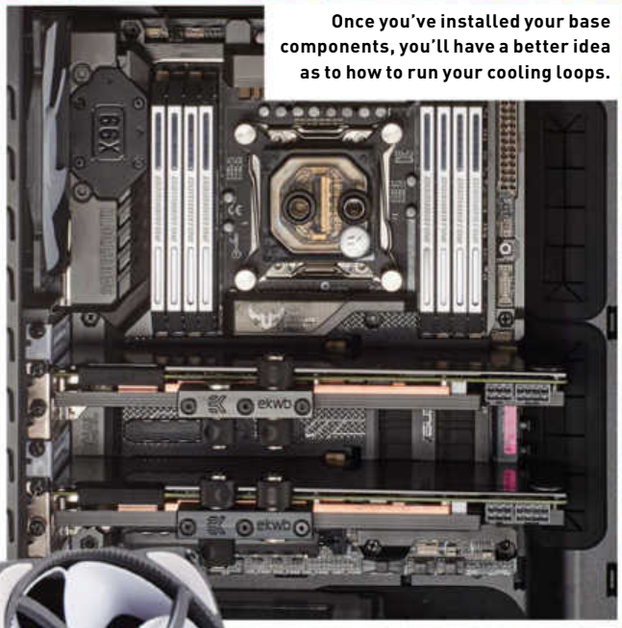
Once you've decided what space your case has for radiators and how many you're going to use, you need to take a closer look at the FPI and thickness of the radiators you'll be using. FPI stands for fins per inch. Essentially, the higher the FPI, the higher the static pressure you're going to need to effectively move cool air through that radiator. For instance, if you have a radiator with an FPI of 38, you'll probably want static pressure-optimised fans. However, if you have deeper radiators with a lower FPI of 16, you won't see any comparable difference between static pressure fans or airflow fans. In fact, in these cases, you're often better off equipping them with airflow fans instead.

WHERE TO BUY?

There isn't a fantastic array of places where you can buy a lot of these components in old Blighty. But one of the largest water-cooling specialists in the country is Overclockers UK (www.overclockers.co.uk), which has a vast selection to choose from. Additionally, if you're a little more patient and want to ensure you're getting EKWB directly from the source, you can buy them straight from EKWB's site (www.ekwb.com). Both of these companies were instrumental in providing us with the hardware to bring this first look to you all.

PLANNING YOUR LOOP

So, at this point, you should be well aware of all the hardware you'll need to be looking at. Next, you want to research which case is best. There's a huge variety out there. In fact, you'll find there'll be water-cooling cases from Mini-ITX chassis all the way up to full E-ATX super towers. Once you've found your case, check what radiators it can support for water cooling. Then you need to think about your tubing and how you're going to cool it – a single loop or dual loops. Once you have all these facts nailed down, your best bet is to sketch out how you want to run your loop, and how many fittings you'll need for all your hardware. Usually, you'll need two fittings per water cooling item – an in and an out.



Once you've installed your base components, you'll have a better idea as to how to run your cooling loops.

We'll admit this isn't the tidiest cabling, but doing a good job at the start will save you time in the long run.

For us, the choice was pretty simple. We'd use the Fractal Define S, a case designed from the ground up for easy water-cooling installation. A dual radiator at the top and a triple rad at the front. On top of this, we'd be using a single closed loop to cool both of the EVGA Superclocked GTX 980 Ti's and the Intel Core i7-5820K. Then it was a matter of tallying up how many fittings we needed, taking into account we'd be using soft tubing and a pump/res combo, as well as planning how our build would look. We'd be using an Asus X99 Sabertooth TUF mobo – stunningly gorgeous and covered in black and grey-plated armour. On top of this, we managed to get a hold of a mixture of black water blocks and fittings. We'd use white coolant to add a little contrast.

CHOOSING THE CHASSIS

Picking the right case can be a tricky business, especially when you're looking to do a water-cooled mod such as this. The best way to do this is to look out for cases designed particularly for water cooling, or by companies who revolve around it. Parvum, Phanteks, Corsair, Caselabs and Fractal are all fantastic case firms that provide some excellent rigs to work and build in, making it easy to create a stunning work of art.

Selecting the right case is undoubtedly the biggest consideration you have to make. It will dictate where your reservoir goes, how many radiators fit and what thickness they are, plus how your tubing runs will work. For instance, we tried to build this particular setup inside of the Phanteks Enthoo Evolv, but we'd already pre-ordered the water-cooling components for a different chassis and they ended up being incompatible with the Phanteks, even though that's a huge case to work in.

> "If you're looking for more flare, invest in angled fittings."

FITTINGS AND LOOPS

And so begins the building process. Of course, like with our regular builds, we generally advise that you build all your PCs outside of the case first, just to see if they work at stock. We individually tested both our GPUs, the memory and the CPU with traditional coolers, before throwing water blocks on any of it.

Then we began the internal build process, stripping the chassis of any unwanted components, such as hard drive bays and cages, and continued to install the motherboard, the memory and the GPUs, securing them firmly to ensure that nothing would fall out or become damaged over the course of our build. We also took this opportunity to install the radiators and plug in the fans where they were necessary. It's also time to attach the reservoir, and install all of the fittings.

CABLE MANAGEMENT

In a build like this, cable management needs to be flawless. The last thing you want is excess, untidy cables cluttering up your rig. Not only will they get in the way of the tubing, they'll also restrict airflow and generally make your tubing routes that little bit more difficult. Cablemod (www.cablemod.com) provides custom-sleeved cables for Be Quiet!, Cooler Master, Corsair, EVGA and Seasonic power supplies. These should spruce up your build quite nicely. Alternatively, it's not impossible to sleeve the cables yourself. This takes a lot more time and patience, but you can include cable combs to keep the cables tidy, plus vary your colour schemes.

Additionally, we used the Phanteks PWM Fan Hub. Threading all five Noiseblocker fans through one fan controller means we can control how much power they receive directly from the CPU fan header, meaning the system will ramp up or down, dependent on CPU temperature (which admittedly will be quite low for this build).

BUILDING AND PRIMING THE LOOP

At this point, it's time to start your tubing runs. Line up a stretch of tubing between the two points you wish to connect, then cut a little more off than you think you'll need. It's better to have too much than too little – you can always shorten the runs later. Next, unscrew one of the fittings, wiggle your tubing onto the fitting and thread the other end of the compression fitting onto the unattached end. Then screw it down, compressing the tubing in place.

If you're struggling to fit the tubing on, use a pair of needle-nose pliers. Gently insert them into the end of the tubing and carefully

It will take time to get your loops right (it took us three attempts to master the bridge between our GPUs). But once it feels snug and secure, you can smash on and start filling your loop. Always throw paper towels underneath everything – they're a good early indicator of a leak.

stretch the tubing slightly, so it's easier to work. Then you'll need to take the sleeve off the other fitting, pre-attach that to your new tube and do the same with the other end. It's then simply a case of running all of the tubes to their correct lines. It doesn't matter which tube goes where, as long as it creates a loop. Once the system is sealed off and pressurised, the temperature of the water will be consistent around the entirety of the loop, regardless of which component goes to which first. Thanks science!

You're now at the scary part – priming your loop. Ensuring that the reservoir is gravity feeding the pump (in other words, it's above), attach one last fitting with a length of tubing onto the top of the reservoir (depending on how you have your reservoir set up, it might be advisable to get a multi-port top adaptor). Then use a funnel to carefully pour your coolant into the loop. In our case, we like to just use a squirty plastic sauce bottle to fill our loop.

Before doing any of this, you want to make sure that everything on your motherboard is unpowered. Ensure that your CPU power, your motherboard ATX power and any power cables heading to your graphics card are all unplugged, either at the power supply end or the hardware's end. Then you'll want to either bridge the two power points on the ATX power with a paper clip, or use a specially designed bridge connector. Then it's simply a case of switching the power on every time you fill the reservoir, until the entire loop is filled. Just remember not to do this until after your reservoir/pump has fluid inside of it.

SPECIFICATIONS

CPU	Intel Core i7-5820K @ 4.4GHz
Motherboard	Asus Sabertooth X99
Memory	64GB Corsair Dominator Platinum (8x 8GB) @ 2,666MHz
Graphics	2x EVGA GeForce GTX 980 Ti Superclocked ACX 2.0+
Storage	2x Samsung 850 Evo 500GB SSD
Case	Fractal Define S
Power supply	Be Quiet Dark Power Pro 11 1,200W – Platinum
Fans	5x Noise Blocker NB-eloop B12-2 120mm fans

CONCLUSION

As you've probably already spotted, the build looks great. Matching the black EK water blocks with the Asus X99 TUF Sabertooth worked out really well, and the white provides a brilliant contrast to the overall style and look.

The temperatures are where we expected them to be. We clocked the Core i7-5820K up to 4.4GHz and recorded temperatures at 55 degrees Celsius under load. The GPUs remained at around 60 degrees under full load and we maintained the fans at a constant 20 per cent speed throughout the system. For performance, we couldn't really get much more out of either the GPUs or the CPU as they were already at their hardware limits. But either way, the performance was still outstanding, and the fact that it remained so quiet even while under high load is really something else.

A worthy mention here is definitely the coolant. We used EK White Pastel coolant to fill our loop and it looks fantastic, even with a soft tubing loop. Our leak test went without a hitch. Although we could only test it for around 45 minutes during the shoot, there was absolutely no spillage. The EK compression fittings ensured an incredibly tight seal around all of the components. That is, as long as you haven't damaged the tubing in the process (especially if you're lazy like us and use scissors). Generally speaking, you should always run a leak test for 24 hours minimum before powering any of the components on, but in our case, we simply didn't have time.

In hindsight, we'd have loved to have gone with hard tubing. It's all the rage at the moment, and rightly so – it's some of the nicest-looking water-cooled work you can do. A larger case would have also been good. One of Caselabs's Magnum SM8s or Parvum's ATX chassis would've been fab – going up to two 360mm radiators instead of just the one and a dual radiator would have been great for additional cooling.

A different chip would have also been nice, just to see if we could push beyond the silicon limits on ours. Thermally, there's no issue with our 5820K, it just won't clock beyond 4.4GHz, but that could have been a different story if we'd gone beyond the 4.7GHz boundary. Additionally, running two loops would've looked stunning. One in black and one in white, separating the GPU and the CPU.

Should *you* be water cooling, though? That was the original question. It depends on your budget. As with any build, hard cash is ultimately what it always comes down to. If you're looking for the best bang for your buck, water cooling with a custom loop just isn't for you. Even if you do it on the relative cheap, you'll still be looking at somewhere around the region of £400, minimum, on top of everything else.

Water cooling is for those looking to build a beautiful and quiet workstation capable of destroying benchmarks and running any task you can throw at it with absolute silent ease. It's not for the faint hearted, and although water cooling has come a long way since the first attempts way back yonder, it's still filled with danger and possible hardware failure. But then, we don't know of any aspect of the PC enthusiast's arsenal that isn't.

THE ULTIMATE
PC Building HANDBOOK

THE BUILDS

WHATEVER YOU'RE PUTTING TOGETHER, WE'VE BEEN THERE

BUILD YOUR PERFECT PC

WHETHER YOU'RE UPGRADING YOUR PC OR STARTING ANEW, THIS IS THE BEST KIT

ONE OF THE JOYS OF OWNING A PC is that you can upgrade it as you go. Need higher frame rates in games? Drop in a newer graphics card. Want more power elsewhere? Grab a new processor or go for that old favourite: the memory boost. There's a wealth of upgrades that can transform your machine, plus you can change slowly over time to suit your budget, so you rarely have to suffer a sluggish rig for long. Every now and then, the best possible upgrade is to dump your current rig and start afresh by building a whole new machine from scratch.

What sort of machine should you build, though? Which items are important? Which work well together? How much should you be budgeting for? That's a lot of questions, and getting the right answers means having to go and research all the current trends in order to make the best decision. Before you do that, though, take a look at our guide. You'll discover that we've taken the hard work out of the equation and presented you with three machines that fit three different budgets. Our budget PC will get you gaming at 1080p for a bargain price, our mainstream machine will cope with pretty much anything at 1440p, and our high-end rig will do pretty much whatever it wants...

On these pages are our recommendations for putting together those budget, mainstream and silly high-end machines. These rigs all include a screen and peripherals in the ticket price, so if you're keeping your existing goodies then you'll have more cash to spend elsewhere. And what's our recommendation if you find yourself with that pleasant problem? Either get a larger SSD or a more powerful GPU. Happy building you lovely people!

HOW TO... BUY A GPU

THE GRAPHICS CARD IS ONE OF THE biggest upgrade purchases you can make for your performance PC. It's also one of the easiest – open up the case, slot it in and power it up. Simple as juicing citrus.

So, making the right choice is vital, especially as there are so many different options around at the moment. Essentially, it's almost entirely down to your budget. Buying the most powerful single-GPU card you can afford is always a good rule of thumb, but it's always worth ensuring that your power supply is capable of feeding it enough juice and has the right connectors.

So long as your PSU has a pair of 8-pin PCIe power connectors, you should be golded, but always check that your PSU's capacity matches the recommended spec for your prospective GPU. Finally, a word on multi-GPU purchases. Beware. You can get better average frame rates, but an equivalently priced single card is always going to be a better experience.

BUDGET

MOTHERBOARD	
MSI B85M-E45	£48
CPU	
Intel Pentium G3258	£51
MEMORY	
Crucial 2x 2GB DDR3 1,600MHz	£20
GRAPHICS CARD	
MSI GTX 750 Ti OC	£100
SOLID-STATE DRIVE	
OCZ ARC 100 240GB	£67
CPU COOLER	
Intel Stock Cooler	N/A
POWER SUPPLY	
Silverstone Strider E 500W	£45
CHASSIS	
Corsair Carbide 200R	£45
OPTICAL DRIVE	
LiteOn IHAS124-14 24x DVD±RW	£12
SCREEN	
AOC E2250SWDNK	£75
TOTAL	**£463**

MAINSTREAM

MOTHERBOARD	
Asus Z97-A	£114
CPU	
Intel Core i5-4690K	£172
MEMORY	
Corsair Vengeance LP 8GB	£46
GRAPHICS CARD	
XFX Radeon R9 290	£220
SOLID-STATE DRIVE	
Crucial MX100 512GB	£150
CPU COOLER	
Enermax ETS-T40	£38
POWER SUPPLY	
OCZ ModXStream Pro 500W	£65
CHASSIS	
Cooler Master CM690	£52
KEYBOARD	
Corsair Vengeance K65	£59
SCREEN	
Viewsonic VX2363Smhl	£125
TOTAL	**£1,041**

HIGH-END

MOTHERBOARD	
Asus X99 Deluxe	£292
CPU	
Intel Core i7-5960X	£800
MEMORY	
Corsair Vengeance LPX 16GB	£101
GRAPHICS CARD	
Nvidia GeForce GTX Titan X	£796
SOLID-STATE DRIVE	
Intel SSD 750 Series 1.2TB	£804
CPU COOLER	
Cooler Master Nepton 240M	£77
POWER SUPPLY	
CM Silent Pro Gold 800W	£135
CHASSIS	
CM Cosmos 2 Ultra	£300
KEYBOARD	
Corsair Vengeance K70	£113
SCREEN	
Philips BDM4065UC	£550
TOTAL	**£3,968**

BUDGET

When every pound counts, spend them wisely

MOTHERBOARD
MSI B85M-45

With the change in Gigabyte's previously impressive B85M-D2V we've switched to the slightly better MSI board for our budget build.

CPU COOLER
Intel Stock Cooler

The Pentium Anniversary chip is a very cool-running CPU, even when overclocked. We managed a stable 4.2GHz on this stock Intel cooler.

MEMORY
Crucial 4GB 1600 DDR3

Memory pricing continues to be incredibly volatile, but it's still a great time to squeeze more sticks into your rig. You really should see 4GB as the minimum.

CPU
Intel Pentium G3258

Poor AMD, it's a clean sweep for Intel on all our recommended rigs. The latest Pentium is simply the best budget chip around right now, offering Haswell for peanuts.

GRAPHICS CARD
MSI GTX 750 Ti OC

Nvidia's budget GPU is quite a feat of engineering because of the wonderful Maxwell architecture. The MSI card is a bargain.

SOLID-STATE DRIVE
OCZ ARC 100 240GB

OCZ's ARC 100 drive may not be the quickest, but it's great value, incredibly consistent and faster than Crucial's MX100 at this capacity.

POWER SUPPLY
SilverStone Strider E

We may be talking about a budget rig here, but it's still a hefty chunk of cash to risk on a no-name power supply. This 500W Silverstone PSU will give you peace of mind and all the PCIe leads you need.

OPTICAL DRIVE
LiteOn IHAS124 DVD+RW

We really wonder whether you actually need an optical drive anymore, but for now we'll err on the side of caution and include one in the list. Don't feel bad if you forget to buy it though.

CHASSIS
Corsair Carbide 200R

Much more impressive than its price tag may lead you to believe, the clean lines and added extras of this chassis make it the budget case to beat. An understated bargain.

SCREEN
AOC E2250SWDNK

This 21.5-inch panel has a native resolution of 1920 x 1080 and looks pretty good despite that ridiculously low price tag. It's no IPS-beater, but it'll do for half the cash.

MAINSTREAM

A stunning rig doesn't have to cost a fortune

MOTHERBOARD
Asus Z97-A

We've seen a lot of Z97 motherboards since this Asus offering landed, but nothing newer has managed to push it off this list. Great features at a great price. Simple really.

CPU
Intel Core i5-4690K

For almost the same price as the old Core i5-4670K, you can pick up a Devil's Canyon CPU. This still get's the nod for us over the new Skylake chips, for value if nothing else.

CPU COOLER
Enermax ETS-T40

Enermax has simply amazed us with this, its first CPU cooler. The performance is excellent, the price is astonishing, it's easy to fit and it isn't so big that it limits your case or mobo choices.

MEMORY
Corsair Vengeance LP 8GB

This pair of 4GB sticks will give you all the performance you could ever want, and they're in stormtrooper white. They'll only take up two slots in the board for upgrading, too.

GRAPHICS CARD
XFX Radeon R9 290

In order to shift units out of the channel, AMD's top cards of the last generation have dropped in price. The R9 290 is great value, if you can't stretch to the 290X.

SOLID-STATE DRIVE
Crucial MX100 512GB

Crucial has made a big splash in the SSD market with this chunky drive. The 512GB version is quicker, larger and cheaper that the pricier M550.

POWER SUPPLY
OCZ ModXStream Pro

If you want to build a performance machine, you're going to need a powerful PSU. This 500W baby will power the rig, with extra to spare. It's quiet as well.

KEYBOARD
Corsair Vengeance K65

We love a good mechanical switch keyboard – clack clack clack clack – and Corsair is making some of the best. The K65 is a great compact option, with a compact price to boot.

CHASSIS
Cooler Master CM690

The CM690 eschews silly gimmicks in favour of producing a no-nonsense chassis that has plenty of cooling options for your mainstream rig. There's space aplenty inside, and all at a reasonable price.

SCREEN
Viewsonic VX2363Smhl

The old 23-inch Viewsonic IPS seems to be EoL now, but this white one has got the budget IPS panel and decent performance for its bargain price tag.

HIGH-END

For when you *really* want to treat yourself

MOTHERBOARD
Asus X99 Deluxe

As usual this Deluxe board from Asus is absolutely stuffed with funky features. It's one of the finest, and best-looking, X99 boards around and not a bad overclocker either.

CPU COOLER
Cooler Master Nepton 240M

Why settle for a reasonable overclock when you can hit 5GHz? This kit is speedy, boasts incredible performance and is quiet in operation. Everything you'd want, in other words.

MEMORY
Corsair Vengeance 16GB

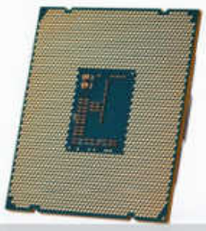
The Haswell-E platform is the first to bring DDR4 to the consumer. That does come at a hefty price, but it's damned quick.

GRAPHICS CARD
Nvidia GTX Titan X

The dual-GPU R9 295X2 is still the quickest overall card, but the GM 200 in the Titan X makes it the best all-rounder. It's almost as quick and will never suffer the ignominy of multi-GPU issues in-game.

CPU
Intel Core i7-5960X

If you're after the fastest, most advanced CPU around, then this 8-core, 16-thread Haswell-E is it. There's also the 6-core i7-5820K for a more reasonable £300, but the 5960X is the pinnacle of modern CPUs.



SOLID-STATE DRIVE
Intel SSD 750 1.2TB

Intel's latest drive is the very first consumer-focused SSD to utilise the new NVMe protocol. And that makes it super-quick, like an Extreme Edition SSD. With a price to match.

POWER SUPPLY
CM Silent Pro Gold 800W

Cooler Master continues to impress with its power supply units, and this wonderful box of tricks is truly one of the best out on the market right now. It'll last you a few upgrades!

KEYBOARD
Corsair Vengeance K70

Corsair's update to the older Vengeance keyboard rights all its older sibling's wrongs. It's also a truly stylish gaming board with the red backlight glowing against its black-brushed metal chassis.

CHASSIS
CM Cosmos 2 Ultra

Cooler Master has always been an impressive maker of cases, but it has truly stunned us with this chassis. Yes, it's expensive, but if you can afford to drop this much on your case, you'll be more than happy.

SCREEN
Philips BDM4065UC

This 40-inch 4K behemoth is the first screen to make us think that super-high resolution actually looks super. It's a decent VA panel and a great price, too, and will really take advantage of the Titan X.

Build A Budget Windows 10 PC

Create your own DirectX 12-ready rig for a piffling £540

Windows 10. Ah, glorious Windows 10. You come bearing many gifts of silicon-enhancing joy. DirectX 12 and a reimagined Start menu, you beautiful things. Sorry, we've been a little bit distracted of late, beta-testing Microsoft's latest platform. It's everything Windows 8 should have been. Still, no point crying over corrupt files. We've moved on. And what's important about Windows 10, more so than any of the tinkering that Microsoft has done with the operating system or Cortana, is the inclusion of DirectX 12. Surely you've heard us rant about the new graphics API by now?

To put it bluntly, think of DX12 as a free graphics card upgrade for everyone. But instead of going from a GTX 660 to a 670, it's more along the lines of a GTX 660 to a 970. Depending on whether you believe Microsoft's engineers or not, that is. But judging by the early results from the overhead API tests (something you really need to witness with your own eyes), it certainly looks promising.

Anyway, all this discussion about DirectX 12 and Windows 10 caused a bit of a row in the office, ending up with a challenge being issued. Assemble a Windows 10 WQHD gaming-ready rig. Easy, you say? Well yes, very. If it's wasn't for the budget. A whole £540. So here we are, with an AMD CPU... just kidding! Sort of. Read on to discover what parts we picked and why, plus how we put them all together.

INGREDIENTS

PART		PRICE
CPU	AMD FX-8320E	£98
CPU cooler	Cooler Master Hyper 212 EVO	£25
Mobo	MSI 970 Gaming ATX AM3+	£73
Memory	Kingston HyperX Savage 8GB (2x 4GB) 1,600MHz	£39
OS storage	Kingston SSDNow V300 Series 120GB 2.5-inch SSD	£40
AD storage	Western Digital RE3 1TB 7,200RPM HDD	£32
GPU	MSI Radeon R9 380 2GB GPU	£157
Case	BitFenix Neos Black/Red mid-tower ATX	£29
PSU	EVGA 600B 600W PSU (Bronze)	£47
TOTAL		£540


MSI
970 GAMING
Kingston
120GB
FURY
HYPER

CPU

AMD FX8320E

£98

Historically, AMD has been the go-to guy for budget builds and cheap gaming CPUs. Recently, however, AMD has pushed more time and effort into developing its Kaveri line. Although boasting impressive integrated graphics in comparison to the competition, Kaveri lacks a great deal of computational power, allowing Intel to dominate the solutions. That being said, you can still find yourself a solid AMD gaming CPU, as long as you're willing to give up native USB 3.0, PCIe Generation 3 and additional SATA 6Gb/s functionality for the sake of budget.

For this build, we settled on an FX-8320E. Despite being an ageing processor, this little beauty's eight cores should be more than enough to drive the latest games at 1080p and beyond. And if DX12's multi-core-loving features are anything to go by, this CPU should be able to pump out some impressive benchmarks later on in its lifetime. The chip comes in at £98, featuring eight cores, 3.2GHz of processing power (turboing up to 4GHz) and support for DDR3 memory up to 2,400MHz on the AM3+ socket. Although not the tsunami of rendering power that you'd find on an Intel chip, the CPU performs admirably for everyday computational tasks.

The alternative solution by Intel would've been the Core i5-4460. Its four cores provide very similar performance, but it isn't overclockable, meaning you won't be able to increase those numbers any time soon. Despite this, it does provide PCIe 3.0, more SATA 6Gb/s ports and native USB 3.0 support, giving it the slight edge when it comes to feature sets.

GPU

MSI R9 380 GAMING

£157

For driving graphics, we couldn't think of a better option than to stick with AMD, as its GPUs offer the best bang for your buck. The driver updates are less frequent, and the software package isn't as strong as Nvidia's, but what truly matters here is horsepower. Pound for pound, this card won't let you down. If you're looking to hammer the frame rates at 1080p, there's no better call.

Featuring a repackaged Hawaii core – the same found in the R9 290 and 390X – plus five billion transistors and 4GB of GDDR5, this card should perform well. Coming in at £157, MSI's R9 380 Gaming is a fantastic choice. The Taiwanese manufacturer is well-known for its military-grade products, and the Twin Frozr aftermarket cooler is one of the best. Chilled, silent and sexy, even the colour scheme matches the classic black and red that's synonymous with gaming. Not so much Win10, but hell, what are we if not gamers first?

The alternative by way of Nvidia's offering would be a GTX 960. Specifically, Asus's GTX 960 STRIX 2GB card. This edition is a bit smaller than our 380, but it performs just as well in games. It just doesn't match that colour scheme quite so well.

RAM

KINGSTON SAVAGE 8GB (2X 4GB) £39

For memory selection, it was a bit of a no-brainer. We went for the default choice: 8GB of DDR3 at 1,600MHz. Pushing money into frequency here certainly wouldn't help us get any more performance out of the graphics card. And, although that extra frequency may help when it comes to higher-end computational tasks, it's simply not worth dropping the additional coin into it at the moment, as we're not intending to use this PC as a professional workstation anyway.

Kingston's HyperX Savage RAM matched our build perfectly. It fit the black and red colour scheme and came in at a competitive price for the kit, slotting itself perfectly into our meagre budget.

CPU COOLER

COOLER MASTER HYPER 212 EVO £25

Let's be realistic here. The FX-8320E is not a super-fast core, certainly not at stock. So, if we can overclock it, we will. And quite frankly, even at stock, the retail cooler that AMD ships with the eight-core processor just doesn't cope very well with that heat. At all. So, with what little budget we had left, we decided to invest in a CPU heatsink worthy of our time.

Ladies and gents, we give you the Cooler Master Hyper 212 EVO. It's not the best-looking heatsink out there. And it's not the most intuitive to put together. But is it solid and dependable? Yes. Will it keep your beans on ice? Well, probably not. But if you're looking for room temperature, it'll do just fine.

MOTHERBOARD

MSI 970 GAMING £73

The mobo, the backbone. After opting for the FX-8350E, we had to find ourselves a suitable solution to house all that power. Unfortunately, finding new mobos in AMD's lineup is quite the challenge. It's certainly less simple than with Intel, where each new chip denotes a new chipset.

The MSI 970 Gaming is a fantastic entry-level gaming motherboard. Featuring support for Crossfire and SLI, as well as DDR3 up to 2,133MHz, and a plethora of SATA connectors (at least, for an AMD board), there's no better choice. Also, guess what? Black and red.

STORAGE

KINGSTON SSDNOW V3 120GB £40

You shouldn't even bother calling yourself a PC enthusiast today if you're not using an SSD for your operating system. The price of flash storage has dropped astronomically over the last couple of years, to the point where you can buy yourself a 120GB Kingston SSDNow V3 for £40. Granted, it'll run a little slower than some of the more premium options out there, but it's a damn sight faster than any HDD, that's for sure.

For additional storage, we threw in a 1TB Western Digital 7,200RPM HDD (£32). This will provide you with plenty of space for all of your games and any additional files you might need to store on your budget build.

CASE

BITFENIX NEOS BLACK/RED

£29

With a £540 budget, it's inevitable that your spec is going to take a hit somewhere. More often than not, this'll be in the chassis department. For us, the choice was obvious. BitFenix does some fantastic, good-looking and value-oriented case options. And the BitFenix Neos comes in at under £30, putting us well within our target budget.

This cheap and cheerful chassis is a small, lightweight and stylish ATX mid-tower. Ideal for our build, it also includes some very intuitive features that you'd not expect to find on a case with this low a price point, such as 2.5-inch and 3.5-inch removable drive bays, the latter of which are toolless. Additionally, if you fancy chipping in a little extra, you can drop another £5 into the windowed edition, which nets you a red LED BitFenix Spectre fan as well.

PSU

EVGA 600W BRONZE

£47

The power supply will always be one of the trickiest components to choose when it comes to building your first rig. The biggest challenge is finding out how much wattage your lovely new PC is going to utilise, and then accommodating for that. Your best bet is to use a calculator. You'll find a fantastic integrated PSU calculator at the top of your selected part's list at www.pcpartpicker.com.

Ideally, the PSU is one of the components into which you should invest as much as you can. In short, if you buy too cheap a power supply and it pops, it could easily take one or all of your components with it. Because of this, and our tight budget, we opted for an EVGA 600+ Bronze. Unfortunately, it's non-modular, but it does give us 600W of power and a bronze efficiency rating, which should be more than enough for our AMD build.

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Time To Get Building

A step-by-step guide to putting your Windows 10 PC together

1 PREPPING FOR YOUR BUILD

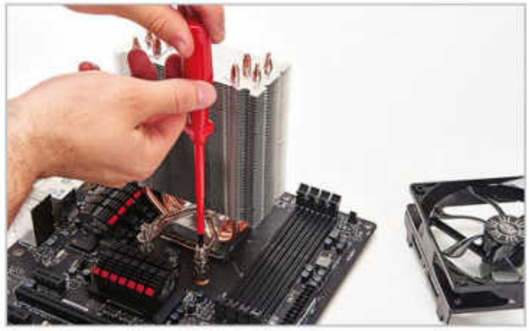
IT'LL PROBABLY come as no surprise, but the best way to build a rig is to plan it well. The first and most crucial aspect of creating your new PC is setting up your build area. Make sure that wherever you decide to construct your machine, the area is free from distraction. Ensure you've all the tools you'll need to put your wee beasty together (usually a Phillips screwdriver, some scissors and a set of needle-nose pliers for the fiddly bits). And last but not least, try to find a static-free area – avoiding woolly socks and carpets is usually best.

If you're paranoid, you can buy an anti-static strap. But if you can't find one, or are feeling stingy, regularly touch the casing around a power supply that's plugged into the wall, but powered off. This will discharge all of the static electricity that you're potentially building up in your body, and may possibly save yourself some heartache later.

2 INSTALLING THE CPU AND HEATSINK

START BY BUILDING your PC outside of the case. If any components are dead, it makes it much easier to diagnose and disassemble. The mobo box also acts as a great anti-static test bench. Start with the CPU. Lift the retention arm on the CPU socket on the mobo, align the FX-8320E with the socket (the golden triangle on one corner of the CPU will match up with the same triangle on the socket). Next, drop it into place, lower the arm back down and lock it in.

Now, the heatsink. Secure the backplate with the nut and bolts. Add a dollop of thermal paste to the middle of the CPU, then carefully position and screw down the heatsink, ensuring the intake of the fan is facing towards the base of the case. Screw the heatsink down in a cross pattern (i.e. diagonally), to ensure you don't put excess pressure on one side of the CPU, potentially bending the pins. Then it's just a case of looping your CPU fan cable around and plugging it into the CPU fan header located above.



3 INSTALLING THE RAM AND GPU

NEXT IS THE MEMORY. Lift the tabs on either side of the DIMM slots, then line up the RAM, matching the gap in the stick to the notch in the mobo. Push them securely into place. Once you hear a satisfying click, you'll know it's correctly seated. It doesn't overly matter which channels you use, but for max performance it's often best to place them one apart (usually colour co-ordinated). Also for this build, you'll want to place them as far away from the heatsink as possible, due to the size of the cooler, while still keeping them in the colour co-ordinated channels.

After this, the graphics card. Gently take your GPU out of its anti-static bag (don't place it on the outside of the bag, as it's conductive and will discharge all of the electricity it's collected). Remove the protective covers on the PCIe connector on the bottom of the card and gently slot it into the top-most PCIe slot. Usually, we'd advise you not to touch the PCB on the back of the card, but due to MSI's inclusion of a snazzy-looking backplate, there's no chance of potentially damaging this little horsey.

4 INSTALLING THE MOBO

ONCE YOU'RE CONFIDENT all your new gaming hardware is working, it's time to throw this bad boy into your chassis. First, pull the GPU out of your mobo (simply move the clip located on the PCIe slot upwards). Next, unpack your case and remove all of the unnecessary components. This means two of the SSD trays can come out, plus two HDD trays and the little welcome pack of screws. After this, take the rear I/O shield out of your mobo box and place it into the rear of your case (make sure it's oriented the right-way around), and push it into the slot at the back of the chassis until it clicks into place all along the edges.

Next, align your mobo with the preinstalled standoffs and screw it down. Remove the two corresponding PCIe slot covers on the back of the case and reinstall your GPU, before securing it with an extra two screws. You'll have to remove BitFenix's ingenious PCIe slot cover – just pull it out and click it back into place once you're done.

5 THE PSU AND CABLE MANAGEMENT

NOW, THE POWER SUPPLY. Remove the case's side panels and slide your PSU in the rear allocated slot. Make sure the fan's facing down, so it can pull air from the underside of the case and exhaust it out the back. Push all of the cables through the space in the bottom of the case.

You'll want to plan which cables go where. The CPU's eight-phase power is hardest – pull it up through the uppermost hole. Run it along the top of the mobo, around the RAM and into the CPU power. The 24-pin power for your mobo can go in the cable-routing hole below the one you've just used for the CPU. Don't force anything, as you'll risk damaging the connector and power supply cable. Then route your front I/O cables around the back and down into the bottom-half of the chassis. Refer to the manual to connect your power/reset buttons and LEDs.

Next, leave three SATA connectors in the rear, and the PCIe power cables in the front. Bundle the remaining cables together with ties and leave them in the bottom of your chassis.

6 INSTALLING THE SSD AND HDD

IT'S NOW TIME to install your hard drives. The BitFenix Neos comes with both 3.5-inch and 2.5-inch drive bays. To install SSDs, pull one of the 2.5-inch drive trays out. Place your SSD inside it (with the connectors facing away from the two finger grips), then secure the drive in place with four screws. Once it's snug, slide the drive back into the cage until it clicks. For the 3.5-inch hard drives, BitFenix has developed an innovative way to secure them. Simply take one of the drive caddies, pull it gently apart, slot the drive in place and push the caddy back together. Again with the connectors facing away from the two finger grips.

Now run two SATA cables from the first two ports on the mobo to your drives. Avoid the cable holes and run them past that panel, around the back of the chassis. Due to the positioning of the cutout, you won't be able to run the cable through the hole. Then connect the two hard drives using the SATA power connector we left behind the case earlier.

7 INSTALLING THE GPU

NEXT UP, you'll want to reseat the GPU again. Simply line it up once more with the PCIe slot and press it firmly into place, without using too much force. Try not to bend the connector, or you'll end up snapping off the connector and ruining not only your GPU, but your motherboard, too.

Then run the two six-pin PCIe power connectors to the card, and install them like you did previously. Additionally, you could use a cable tie here to make sure the PCIe power is nice and cosy. It isn't entirely necessary to cable tie everything down, but it's always advisable to do it where you can, as it improves airflow and generally looks better. It's also a hell of a lot easier to see what you're doing if you need to make modifications in the future, or if you need to clean out your PC.

8 FRONT I/O CONNECTORS

NOW FOR THOSE pesky front I/O connectors. The cables should be positioned through the bottom of the chassis. Run the HD audio as far down as you can get it, then along the bottom of the mobo and into the HD audio connector on the bottom-left of the motherboard.

Next, grab the USB 3.0 cable, and do a similar run. You'll find the USB 3.0 connector isn't located like it is on Intel boards – it's in the bottom-middle of the mobo. The USB 2.0 cable can be plugged into the right of the USB 3.0 cable. And finally, the front power and reset switches. These aren't labelled on the mobo, due to AMD's ageing platform. Refer to the manual for the correct positioning of each pin. You can then secure the side panels back on to the chassis.

9 INSTALL WINDOWS 10

WE'VE ALWAYS FOUND the best way to install Win10 is via a fresh install using a USB stick. Get the ISO via your Microsoft account. Then insert a USB stick (8GB is the usual minimum) and use Microsoft's Media Creation Tool to create a bootable disk. A forewarning that the USB stick will be formatted, so make sure any data on there is backed-up.

Once you've created your bootable media disk, plug it into a USB 2.0 port at the back of your PC. (If you're running Intel, you should plug it into USB 3.0.) Then boot your PC and make your way to the BIOS. Find the USB stick in the boot-order lineup (top of your screen), and drag it to the far-left. Then hit [F10], save settings and apply, and let your PC boot into Windows. Once you're in, you're going to want to jump onto another PC, laptop or phone, head to http://bit.ly/1TljD0d and download the Win10 LAN drivers onto a USB stick. Install them on your rig, update the rest of your drivers, and voila, most of your work is done.

10 INSTALLING PROGRAMS

A QUICK AND EASY way to install a lot of common-use programs is a website called Ninite. It's incredibly straightforward to use, and something we use almost every day. Head to www.ninite.com, select which programs you want to install, and select "Get Installer".

Ninite will then download its installer and automatically install those programs, ensuring you get the most up-to-date software available. Adware free, no hidden secrets. (It makes money from a B2B product, so don't worry!) Then it's just a case of installing some of your more bespoke favourite programs, and you're good to go!

1 The toolless 3.5-inch bays make it incredibly easy to install any additional hard drives you might have, allowing for a total of three.

2 BitFenix even includes 5.25-inch toolless bays. If you really do need an optical drive, you could throw one in here with relative ease.

3 A modular power supply would have been nice here, but the EVGA 600B is brilliant value and comes with a great warranty.

4 The Neos also has support for two 120mm fans in the front of the chassis, which is ideal for such a hot system like this one.

GAME ON

IF YOU'VE COME THIS FAR, you'll have one hell of a rig. For price to performance, it's not going to get much better than this – it'll wipe the floor with consoles at entry level. You're already playing games way above 30fps at 1080p, and if you turn down some of the anti-aliasing, or the more intensive effects, it's viable to game at 1440p and comfortably hit the 40-50fps mark. It's a little different at 4K, of course, but then you're pushing twice as many pixels – both the CPU and the GPU bottleneck the system at this point.

Building inside of the BitFenix was surprisingly simple. Although it does lack some mod cons, for £30 it's an impressive chassis. Yes, it's a little flimsy and the panels require some love, but is it stylish? Yes. Is it easy to build in? Well, yes. There weren't any major setbacks, other than possibly the lack of upper cable-routing holes. Fan support, however, is very limited, but the fact it comes with SSD support and toolless 5.25-inch and 3.5-inch drive cages is incredible at this price.

THE ALTERNATIVE? Intel remains a viable solution. We spent £4 more, so £544, by ditching the CPU cooler and switching in a Core i5-4460 CPU, an Asus H81 Gamer ATX LGA1150 mobo, an Asus GTX 960 2GB GPU and dropping the PSU by 100W.

You pay the Intel premium, but you're only losing out on a CPU cooler and 100W of power that you're not going to need. Considering you won't be overclocking a Core i5-4460 anytime soon, this shouldn't be a worry. And the fact you're using less energy to run your little monster, the cost difference should even out over its life.

WHERE TO INVEST? While working on this budget gaming build, BitFenix offered us the windowed edition of this chassis. However, adding even an extra £4 wasn't viable for our budget. That being said, this build is colour co-ordinated, and MSI has made one hell of a good-looking GPU. We'd struggle not to suggest buying the windowed edition instead.

Unfortunately, this case can get incredibly warm. So much so that, on occasion, it feels like you're contributing to global warming. The GPU in particular, especially when overclocked, gets quite toasty at around 80°C. That's quite hot for any aftermarket cooler. This is in no way MSI's fault. It's more because we overclocked the hell out of it and there aren't any air intake fans by default on this chassis. So that would be our final suggestion. If you've a few extra quid, throw in a nice set of fans, a windowed-edition chassis, and possibly a Corsair Hydro H60v2, or something along them lines, just to keep the CPU temps down.

GAMING BENCHMARKS

3DMark FireStrike (index @1080p)	7,047
Bioshock Infinite (@1080p)	9 / 97
Project Cars (@1080p)	35 / 46
Metro: Last Light (@1080p)	12 / 38
Total War: Attila (@1080p)	6 / 23
Shadow of Mordor (@1080p)	7 / 34
3DMark FireStrike (index @1440p)	3,943
Bioshock Infinite (@1440p)	7 / 71
Project Cars (@1440p)	32 / 39
Metro: Last Light (@1440p)	12 / 23
Total War: Attila (@1440p)	1 / 24
Shadow of Mordor (@1440p)	7 / 25

All games tested at Max Settings with x4 anti-aliasing. GPU overclocked to 10 per cent lower than community max. Game scores are minimum frame rate, followed by average frame rate.

SYSTEM BENCHMARKS

	AMD Feature Build	Falcon Core V51 Mesh Gaming PC
Cinebench R15 (index)	507	**601**
PCMark 8 (index)	2,665	**3,998**

Best scores are bolded. The Falcon has a Core i5-4690K, 16GB DDR3 at 1,600MHz and a GTX 970.

TWICE AS NICE: QUIETLY DOES IT

FITTING MULTIPLE RADIATORS INTO A NEW MID-TOWER CASE FROM FRACTAL DESIGN

LENGTH OF TIME: **1–3 HOURS**

LEVEL OF DIFFICULTY: **MEDIUM**

THE MISSION

Here we're building a nice gaming system that doesn't break the bank, built inside a relatively conventional mid-tower case. But there's still some new and interesting hardware in the mix, of course. Expect nothing less. We have minty-fresh gear from Fractal Design, Corsair and Asus for your perusal. This build is also oriented towards low noise, so those of you with sensitive ears will certainly want to check it out.

NOT LOUD, STILL PROUD

WHEN YOU'RE TRYING to cut down on noise generation, the biggest factor is your case. Fractal Design recently released the Define R5, which is a mid-tower with pre-installed noise absorption panels on the sides and front. The top of it uses the company's 'ModuVent' system, which features modular panels with their own sound absorption that you can pop out to mount fans. We've had great success in the noise department with the R4, and this line of cases is quite roomy and sturdily built as well. Perfect for our needs.

The funky-looking graphics card in there is the Radeon R9 295X2. This has two 290X GPUs in it, and an integrated water-cooling system with a 120mm radiator and fan. We moved some things around to make room for its cooling. Since it only costs around £520, despite being one of the fastest single cards available (Nvidia's Titan Z was apparently a limited run), it seemed like a no-brainer.

It needs some hefty power, of course, so we're adding our trusty 800W Cooler Master Silent Pro Gold. This – along with an Intel Core i7-4790K, 2x 4GB of low-profile Corsair DDR3 RAM, a 480GB SanDisk Extreme II SSD and a 4TB WD Black Edition – gets plugged into an Asus Z97 Pro Gamer motherboard, which we should be able to overclock respectably. We've also added a 120mm Noctua fan to the front of the case. Otherwise, we'd have just the one 140mm pre-installed fan in that spot.

INGREDIENTS

PART		PRICE
Case	Fractal Design Define R5	£87
PSU	Cooler Master Silent Pro Gold 800W	£100
Mobo	Asus Z97 Pro Gamer	£107
CPU	Intel Core i7-4790K 4GHz	£267
GPU	AMD Radeon R9 295X2	£520
RAM	2x 4GB low-profile Corsair DDR3	£49
SSD	SanDisk Extreme II 480GB	£222
HDD	Western Digital Black 4TB	£134
OS	Windows 8.1 64-bit OEM	£77
Total		£1,563

1 PANEL BEATING

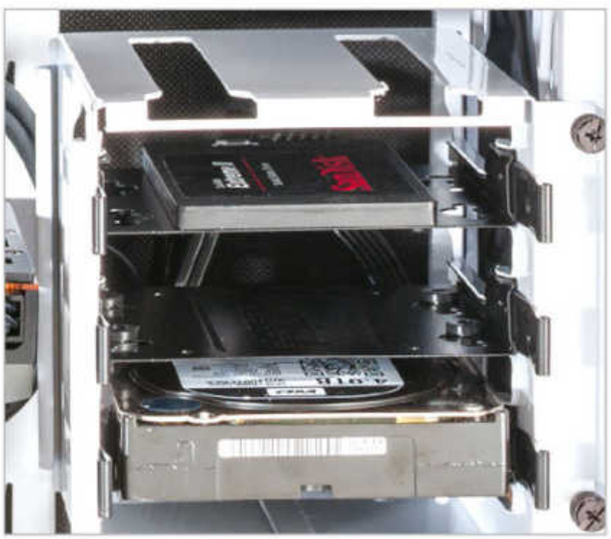
THIS SWITCH IS NEW to Fractal Design cases. When you press down, it releases two catches that hold the side panel onto the case. That means you have toolless entry with just an easy flick. You can optionally add two screws if you're worried about your resident poltergeist taking a liking to it and popping out the panel whenever it fancies a chat.

Under ordinary circumstances, however, it's not possible to get in without pushing down on this widget. Unfortunately, getting the side panel back on proves quite a fiddly process, so this might not be the ideal chassis for first-time gearheads hoping to keep things simple. It's also important to remember that the sound-absorption layer adds a decent amount of weight, so you need to grip the panel firmly on removal, or you could find yourself scraping a new pattern into your desk.

2 HARD CASE

THIS CASE actually comes with three drive cages with a total of 10 drive trays. All cages are removable, even the 5.25-inch cage at the top. We kept only the smaller 3.5-inch drive cage and lifted it to a higher mounting point to make room for the graphics card's radiator down below. We could have tossed all the drive cages, because there are two 2.5-inch mounts behind the motherboard, but then there would be nowhere to install the WD drive.

The chassis comes with silicone grommets that you can slide into a drive tray to absorb the vibration of a mechanical drive, and each tray can take a 2.5-inch drive as well. All of the trays are metal (which is rare), so you don't have to worry about snapping bits off through rough handling or dropping on the floor. And because this case is so wide, you don't need right-angle cables in the back.



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3 SCREAMING FANS

WITH THE DRIVE CAGE elevated several inches, we have enough clearance to install the graphics card's radiator. The rad gets screwed in from below, after sliding out the dust filter underneath the case to make way for installation. We had some concern that the air coming from the case's front intake fan would get sucked into the rad's fan, which would mean less airflow across the motherboard, so we added a 120mm Noctua fan in front to provide more cooling. We also could have removed the ModuVent on the side to install a case fan there, but that would increase the noise level.

4 ACCESS ALL AREAS

THE LARGER FAN in the top of this image is 140mm and comes pre-installed. You can lift the dust filter away to access the whole front area. There are notches on the right of the fan mounts to feed their cables back into the case. At that point, you can connect them to the case's integrated three-speed fan controller, or plug them into mobo fan headers, if available. We opted for the controller. It gets juice from your power supply via a SATA power connector.

You may have noticed there are no grills on the front. Instead, the R5 has vents on the sides to pull in air. This way, it can dedicate the front to a slab of noise-absorbing material. It's pretty slick. If you don't care about that, you can remove the door. It's just attached with a couple of screws.

5 WIDE LOAD

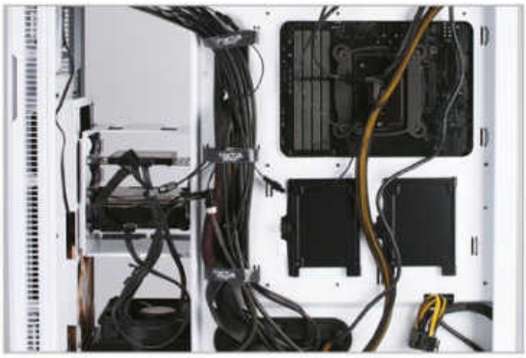
FROM ABOVE, you can see just how wide this case is. Those black screws are attached to a standard 240mm radiator (that of the H100i GTX that's cooling our CPU). Why would you want to shift everything to one side? That way, you don't have to worry about large motherboard heatsinks or tall RAM sticks blocking the installation of a radiator and its fans. There's plenty of room to now add a second set of fans to the radiator, which is pretty rare for a mid-tower. And there's room for a 360mm rad if you remove the 5.25-inch drive cage.

We installed the fans below the rad, pushing its heat out of the case. This is much easier than trying to sandwich the fans between the rad and the top of the case in a "pull" formation. Some cases have extra-wide mounting holes designed for case fan screws, but Fractal Design seems to understand that this location is more likely to be used for installing a radiator, so we had no issues there.

6 NICE AND TIDY

WE COULD TAKE CREDIT for the cleanliness, but it turns out Fractal pre-routed the cables coming in from the front (things like two USB 2.0 ports, two USB 3.0 ports, headphones and mic) and strapped them down with these Velcro straps. We just had to take their lead, loosening the straps to make room for a 24-pin power cable.

The mobo tray is sunken compared to the R4, so there's less play behind it. That gives you the radiator clearance we talked about, and also allows taller air coolers. We can still send a rounded 8-pin CPU cable back here without contortions. You'll note a similar-looking cable down below. This is for PCIe power. It's integrated into the power supply, so we can't remove it. We went with two modular cables because they were flat (and so more flexible) plus all-black (making them less noticeable). We hooked up the fan controller and two drives with a single SATA cable.



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1 The top of the case can take a 280mm radiator, but only if it's mounted toward the front, since the screw holes are too close to the rear.

2 We put grommets in the drive tray that we didn't use, in case we wanted to add a hard drive later and couldn't find the little bag that holds these widgets.

3 Despite this graphics card being about 12 inches long, there's still clearance between it and the drive cage.

4 We used this 295X2 in a previous build, which is why it has the sleeved tubing. The 'stock' version has bare tubes.

ROCKET RIG

OVERALL, this system felt like a solid gaming machine. We got an average of 145 frames per second in *Batman: Arkham City*, with all settings cranked up at 2560 x 1600 (other than Nvidia's proprietary PhysX). When running the graphics card benchmarks, the 295X2's radiator pumped out a lot of heat through the bottom of the case, as expected, but the lower intake fan on the front of the case recirculated a minimal amount of that, thankfully. The best orientation for the rad would probably be on the top of the case or the side, if possible, since heat rises. But the bottom mount seems to do well in a pinch. And our 800-watt power supply had no trouble dealing with the hefty power requirements of this graphics card.

Corsair's H100i GTX performed admirably, its fans hardly spinning up no matter what load we put on the CPU, which was overclocked from 4GHz to 4.4GHz and didn't go past 73 degrees Celsius. We probably could have pushed it to 4.5GHz, but we prefer being confident about the stability of the system rather than cranking it up as hard as we can and quickly running a test before it locks up. That can be fun, but it's not representative. And with this radiator, the chamber on the side that connects to the tubes was a little wider than we anticipated, and the case's rear exhaust fan obstructed it. That's why the tubes are coming out on the 'far' end, with the pump logo upside-down.

Our fresh system is also super-snappy, allowing a full reboot cycle in less than 20 seconds. So you can get into the BIOS, make a tweak and be back to Windows in a flash. The motherboard initially wouldn't let us boot at all, because we didn't have anything plugged into the CPU fan header (the cooler's fans plug directly into the pump). We had to hunt around before we found the setting to ignore that header altogether, but it's an important safety measure to have. By default, a system will shut down if the CPU gets too hot, but you can override that – at which point you better have everything plugged in correctly.

Despite its rocket-fuelled performance, this system is a bit slower than our test rig in some tests, even with its higher clockspeed. That's because the i7-3930K has two extra cores – and a price tag of about £440. At about £270, the 4790K is not bad value.

BENCHMARKS

	TEST RIG	
Premiere Pro CS6 (sec)	2,000	2,327 (-16.4%)
Stitch.Efx 2.0 (sec)	831	766 (8.5%)
ProShow Producer 5.0 (sec)	1,446	1,270 (13.9%)
x264 HD 5.0 (fps)	21.1	19 (-11%)
Batman: Arkham City (fps)	76	145 (91%)
3DMark 11 Extreme	5,847	7,883 (34.8%)

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100% 110%

Our comparison rig consists of a hexa-core 3.2GHz Core i7-3930K (turbo 3.8GHz), 16GB of Corsair DDR3/1600, on an Asus Sabertooth X79 motherboard. We are running a GeForce GTX 690, an OCZ Vertex 3 SSD and 64-bit Windows 7 Professional.

LITTLE PC ON THE PRAIRIE

A BUDGET GAMING PC WITH 1080P MUSCLE AND ROOM TO GROW

LENGTH OF TIME: **1–3 HOURS**

LEVEL OF DIFFICULTY: **EASY**

THE MISSION

A LETTER came in to us from retired army man Harley Roam, who expressed that he's not one with deep pockets. Typically we tend to build rigs in the £1,000 range or more. Often, much more. But Harley was wondering if we could build a PC for under £500. Not just any PC, however. He likes a game, does Harley, so playing at 1080p is important, as is having lots of potential for the rig to evolve as the money drips in.

Challenge accepted, we thought. Couldn't be all that hard, now, could it? Sure enough, you can quite easily build a PC for that price. But it's sluggish, and we don't want that for Harley. Plus, there's some areas in which we simply don't like to compromise. We wanted to make sure he could actually *enjoy* his games. We also wanted to build a system that would have room for relatively inexpensive upgrades. We think we managed all that for a handful of nuggets below the target.

We did the best we could to make sure Harley could build a good rig for as little scratch as we could bear. After all, we've all been in a spot where we weren't exactly flush with cash. So, pay attention, Harley, this build's for you!

RALLY THE TROOPS

SETTING A BUDGET OF £500 puts severe restrictions on our choices of hardware, and ultimately, we only just made it. There are some things we just weren't willing to bend on, namely 1080p gaming with at least 30fps with settings cranked up. This led us to pick the GeForce GTX 960 for the GPU. We went with an Asus STRIX because we found it for about £170. While that's a big chunk of budget, it will give a solid gaming experience in many games you're likely to encounter. Going with team green also means you'll have a better experience in Linux gaming, should you choose to go with the free OS. After all, including Windows 8 in a build means saying bye-bye to an extra £80. If you're building an ultra-budget machine, it's unlikely you're keen to fritter away that sort of cash.

For a processor, we went with an AMD FX-6300, which was £80. Between the GPU and CPU, we thought this would give Harvey a good base to build upon. We dropped the CPU and GPU onto a Gigabyte GA-970A-DS3P, which was about £50. We also dropped the idea of having an SSD or optical drive. The power supply is a little beefier than our needs called for, but we wanted to make sure the system could take an upgrade or two without hitting the upper limit of the PSU. The Enermax case we put everything into was surprisingly roomy for the build, and gave enough options for cable management and upgrades that meant we weren't left wanting.

INGREDIENTS

PART		PRICE
Case	Enermax ECA3290A-G Mid-tower ATX	£40
Mobo	Gigabyte 970A-DS3P	£54
CPU	AMD FX-6300	£79
Memory	G.Skill Ripjaws 8GB 1,866 DDR3	£59
GPU	Asus STRIX GTX 960	£170
PSU	Corsair CX500	£53
HDD	Seagate Barracuda 1TB HDD	£40
Total		£495

1 CUTTING THE POWER

CORSAIR'S CX500 isn't as sexy as its modular siblings, but it gets the job done for a reasonable price. Normally, a non-modular power supply means a rat's nest of unused cables. We kept things tidy with the help of the case's bevelled side panel behind the mobo. A few zip and twisty ties kept the unused power cables out of the way.

The CX500's meagre (to us) output means it's small compared with the 1KW monsters you'll find in bigger systems. That's acceptable because our CPU and GPU aren't super demanding. The PSU is 80 Plus Bronze certified, which is a bare minimum when it comes to efficiency. If you do eventually upgrade to a bigger PSU, we prefer modular units to help keep things neat. Power cables are the largest cables in the case, and more of them makes maintaining good airflow and closing the right side panel a pain.

2 TAKING IT EASY

NOTHING FANCY to see here, folks – move along, move along. Our limited budget prohibited us from going mad on cooling, so the stock heatsink and fan had to suffice. It wasn't so bad though; the FX-6300 stayed fairly cool with the stock parts. Even under load, it didn't feel like the processor was heating up the room. We didn't plan on overclocking the CPU, so excessive cooling wasn't warranted here. Using the stock heatsink and fan also saves you a bit of build time, since you don't have to worry about installing custom backplates or radiators.

Of course, should you want to OC, we'd recommend grabbing an aftermarket cooler. For air cooling, Cooler Master's Hyper 212 Evo is only £25 and will get the job done as long as you don't go too crazy. If you're looking at getting a beefier CPU or doing heavier overclocking, we prefer closed-loop water coolers.

3 A SIMPLE KIND OF MOBO

GIGABYTE'S 970A-DS3P is a £54 motherboard that has all the basics you need. That said, our choice of mobo was a compromise due to our budget constraints. One thing we noticed about this particular board is that the right side didn't extend all the way to the forward column of brass standoffs. This meant that plugging in the ATX power connector was a little more hairy, as the board flexed a bit under the pressure. That was easily overcome by pushing the underside of the board with the other hand, though. Still, it was a bit of a gotcha you should keep in mind if you go with this board.

The motherboard is one of the parts that we consider 'good enough for now', knowing that a user would probably want to upgrade it in the future. It's got all the basics, USB 3.0 and other standards like onboard FakeRAID. You can find good AMD 970 chipset boards for around £70, and 990 boards for a little more.

4 TAKE IT EASY

ONE GREAT THING about going with a stock heatsink and fan is that memory is a real breeze to install. Click-click, bam! Done! For this build, we went with 1,866MHz G.Skill Ripjaws, which the motherboard took without needing to overclock. We had to set the memory speed in the BIOS, but that's a relatively painless process. Eight gigabytes of memory is certainly plenty for this build. Again, we weren't trying to go crazy. To stay within the budget range, we don't recommend going much higher in capacity or frequency.

The G.Skill Ripjaws aren't the cheapest DIMMs you can find, but they are relatively inexpensive, have decent timings and will serve you well even if the CPU, motherboard or other components are upgraded. While 1,600MHz memory is slightly cheaper, the 970 chipset and CPU support 1,866MHz without overclocking, so we figured, why not? If you have to squeeze every penny though, 1,600MHz memory is just dandy.

5 THE LONE HARD DRIVE

THIS IS A BUDGET BUILD, so we chose to omit use of an SSD in favour of a single spinning drive. The 1TB Seagate Barracuda looks kind of lonely, but that also means the drive will have plenty of room to dissipate any heat.

Building systems with spinning hard drives as the system drive is a bit antiquated. Compared with SSDs, waiting on big file transfers feels like going back to the stone ages. Unfortunately – or fortunately, depending on how you look at it – prices for spinning hard drives don't scale at the same rate capacity does. Where a 500GB SSD might cost the same as two 250GB models, a 1TB HDD is usually less expensive than two 500GB units. That price difference precluded us from using RAID as a strategy to obtain higher transfer rates. For that reason, we recommend upgrading to an SSD as soon as there's spare money to burn.

6 SEE THE SIGHTS

THE GRAPHICS CARD we chose is modest by many counts. Nevertheless, the GTX 960 can still produce playable frame rates at 1080p for a wide array of games. Don't think you'll be playing *Grand Theft Auto V* maxed out, but you can still get good-looking visuals for a pretty reasonable £170.

The Asus STRIX implementation of the GTX 960 is quite the compact card. The STRIX's size would pay off a lot more in a smaller, tighter system like an HTPC. But in the Enermax case, the card has plenty of room, making for a simple installation and power connection. The card is also inexpensive enough that buying another one down the road and using the two in SLI is a perfectly viable upgrade.

You'll have an easy time getting the card to work in Linux, as Nvidia's proprietary drivers are still the best performers on the open-source OS. So you'll be able to play *BioShock: Infinite* on Linux, should you go the way of the penguin.

1 It's rare that we leave a CPU with nothing more than a stock heatsink and fan, but we can get away with it since we're not overclocking.

2 The lack of an optical drive is not a crime. You can find Linux install media on USB drives, and if you need a DVD drive for Windows 8, you can pick one up for about £15.

3 The 2.5-inch drive cage positioned above the 3.5-inch cage gives extra room for long graphics cards that otherwise wouldn't fit.

4 The CX500 isn't modular, so you have to stuff the extra cables somewhere. The case's bevelled side panels make this easier for rookies.

WIDE-OPEN SPACES WITH ROOM TO GROW

PENNY-PINCHING to the extreme isn't something we normally do around these parts. We – and many of our regular correspondents – just love our big cases and pricey CPUs, but we get that not everyone can afford to build in the £1,000-plus range.

At the same time, if we're going to compromise in the name of budget, there are some things we just aren't willing to skimp on. Even with a relatively modest £80 CPU, gaming relies heavily on GPU performance. Investing that £170 in a GPU will pay off in the long run, as other components are upgraded.

Building PCs is about more than just performance, it's a hobby and passion for us. If money is tight, it's sometimes better to get a modest base and improve it over time. That will make a story out of the continual work. Just as a project car can go from rust-bucket to show material, a computer can go from a budget build to a face-melting machine that bends space-time given enough effort, blood, sweat, tears and disposable income.

We wanted to create a solid base to build on. The case offers plenty of opportunities for expansion, and the GPU and CPU combo will get the system started in the right direction. While the build drags its ass for a number of reasons – namely, the modest CPU and a spinning hard drive for the OS – the six cores of the FX-6300 combine to get work done in multi-threaded applications. Also, you should be able to play quite a few games at 1080p at resonable settings with the GTX 960.

Transforming this build from modest to mighty can take any number of approaches with incremental improvements. An SSD will level-up your data-transfer speeds significantly, and is the best way to enhance the build. The boost in storage speed should be followed by a more robust motherboard with features like M.2 support. A mobo upgrade will present the choice to stay with the AM3+ socket or to switch over to Intel.

If you choose to stay with AM3+ and go with a better AMD CPU or overclock the FX-6300, investing in a closed-loop water cooler is ideal. Packing in more case fans will make life easier for overclockers, as well. With this case, there's plenty of room for a small cooler and extra fans. Going with Intel will cost you some extra coin, but will allow for a less aggressive cooling solution.

We enjoyed this challenge, even if it was a struggle to dip below £500. We wanted to make sure Harley would have a better base machine for gaming and video. Prices do fluctuate, and we saw a few deals that brought the build down by £30 or so. By the time you read this, maybe you'll be lucky enough to take advantage of a couple of specials and get started. Happy trails!

BENCHMARKS

	TEST RIG	
Premiere Pro CS6 (sec)	2,000	2,194 (-9.7%)
Stitch.Efx 2.0 (sec)	831	1,685 (-102.8%)
ProShow Producer 5.0 (sec)	1,446	1,717 (-18.7%)
x264 HD 5.0 (fps)	21.1	9.9 (-53.1%)
Batman: Arkham City (fps)	76	39 (-48.7%)
3DMark 11 Extreme	5,847	3,294 (-43.7%)

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100% 110%

Our comparison rig consists of a hexa-core 3.2GHz Core i7-3930K (turbo 3.8GHz), 16GB of Corsair DDR3/1600, on an Asus Sabertooth X79 motherboard. We're running a GeForce GTX 690, an OCZ Vertex 3 SSD and 64-bit Windows 7 Professional.

VIRTUALLY PREPARED: GETTING READY FOR OCULUS RIFT

WELCOME TO THE WILD WEST OF VR

LENGTH OF TIME: **1–3 HOURS**

LEVEL OF DIFFICULTY: **MEDIUM**

THE MISSION

VIRTUAL REALITY is a hot topic for PCs right now, and everyone wants a piece of the action. It's a Wild West free-for-all as different hardware and platforms are announced, so putting together a gaming rig that can handle the demands of the upcoming VR setups is a real concern. Oculus VR has recently helped clear the air by publishing the recommended specs for its Rift platform. Depending on your current system, the recommended hardware either looks moderately tame or outlandishly extravagant. The core components consist of the CPU, GPU and RAM: Core i5-4590, GTX 970 or R9 290 and at least 8GB.

If you want to minimise on costs, you could easily build a complete Oculus-ready system for around £700, including the OS, but we view these recommendations as more of a minimum, rather than a long-term solution. No one likes to be caught unprepared when the inevitable next round of updates shows up, so we set about building a rig that has some room for upgrades down the road. Our baseline rig meets the Oculus recommendations, and when Oculus 2.0 doubles down in a year or two, you'll be ready. Trusty screwdriver in hand, let's get building.

SADDLE UP

IN THEORY, all you need to get started with building a VR-capable rig is any computer case to house your components, but a poor choice can leave your rig pushing up daisies in short order. If you want to be going strong for several years, you'll need something more capable. We've opted for a larger case that offers plenty of room for expansion; we also chose a slightly faster processor, a motherboard that can support a second GPU, and included an SSD, which ought to be required for any new PC in this day and age.

The case is Antec's shiny-new P380, an understated yet attractive design with plenty of room that doesn't make a lot of noise. Our graphics card is the diminutive Asus GTX 970 DirectCU Mini, packing a lot of power into a small package while using much less juice than the AMD R9 290. The CPU is Intel's i7-4790K, cooled by the Cooler Master Hyper 212 EVO, though the i5-4690K could save you £90 without hurting gaming performance. ASRock's Z97 Extreme6 mobo is good value, and if you want wireless AC integrated into the board, check out its similarly priced Extreme6/ac. Either one makes adding a second GPU simple. Powering the system is the Corsair CX500, a compact but non-modular PSU. We used some generic DDR3-1600 memory, as RAM typically has little impact on real-world performance. Wrapping things up, we went with a 250GB Samsung 850 EVO SSD and a 2TB Hitachi HDD.

INGREDIENTS

PART		PRICE
Case	Antec P380	£135
PSU	Corsair CX500	£47
Mobo	ASRock Extreme6 Z97	£135
CPU	Intel Core i7-4790K	£268
Cooler	Cooler Master Hyper 212 Evo	£25
GPU	Asus GTX 970 DirectCU Mini OC	£279
RAM	2x 4GB DDR3-1600	£38
SSD	Samsung EVO 850 250GB	£77
HDD	Hitachi Ultrastar A7K2000 2TB	£59
OS	Windows 8.1 64-bit OEM	£76
Total		£1,139

1 TRUE GRIT

AT THE TIME WE PUT together this guide Intel had just released its desktop Broadwell chips. The good news is that the Core i5-5675C works fine in the ASRock Z97 Extreme6 mobo we've selected; the bad news is that the Iris Pro 6200 graphics and reduced CPU clockspeeds aren't really an upgrade for those using a discrete GPU.

Skylake, obviously, provides some improved performance, but it also requires a new motherboard and memory. Bottom line: When building this, we had to build with the best parts that were shipping, so we stuck with Haswell. The past several generations of CPUs from Intel haven't radically altered CPU performance, and Broadwell doesn't change that, so the Core i7-4790K should keep you happily gaming for years to come.

2 YOUNG GUNS

IF YOU'RE A NEW CONVERT to the exciting world of putting together your own PCs, then it's often advisable to mount your cooler prior to installing the motherboard into the case. This Antec chassis has a cutout on the back, meaning that you could do it either way you please. However, larger air coolers such as the Hyper 212 Evo can be a bit finicky to install, so it's often best to take care of it first, either way.

We could've also skipped the aftermarket cooling altogether, as we're running stock CPU clocks. There's nothing wrong with that approach, but the larger fan on the Hyper 212 EVO cooler makes a fair bit less noise and will certainly keep the CPU nice and frosty. It's also not so massive that it will interfere with the DIMMs, though the side-facing fan isn't going to provide an awful lot of airflow to the RAM or motherboard heatsinks.

3 HANG 'EM HIGH

THE P380 COMES WITH THREE FANS – two 140mm at the top and one 120mm at the back – each with a speed selector. All three fans come pre-installed near the top-left of the case, venting hot air. That means Antec is using negative pressure cooling by default, which often has the undesirable side effect of pulling dust in through every crack and seam over time. We didn't add any intake fans for this build, but there's room for a couple of 140mm (or three 120mm) fans on the front panel.

If you want to use liquid cooling, there's also room at the top and back for radiators. The P380 has an integrated fan power hub on the back, but it's there purely for providing power. It would have been nice if Antec had included external fan-speed switches, but cooling worked well enough even with all three fans set to low speed.

4 TAKE IT EASY

THERE ARE TWO MAIN PHILOSOPHIES when it comes to wiring your case. Some want a pristine-looking wiring job, and others just tuck everything out of the way and call it good. The drawback of cleaning up the wiring too much is that if you then need to add another component, you're often stuck undoing your earlier work and then tidying up again.

For frequent upgrades, it's easier to not spend too much effort on the 'hidden' wires – it's not like anyone looks at the back of your motherboard. Also notice that the 8-pin EPS12V cable for the CPU has to reach quite far, and the 26-inch cable on the CX500 makes this easy. A PSU with a 22-inch CPU cable probably wouldn't be able to route behind the motherboard.

5 THE LONE RANGER

OUR SINGLE GTX 970 is so small in this cavernous case that it looks a bit lonely. Smaller cases might require that you remove one of the hard-drive cages to fit longer GPUs, but not the P380. If you want to add a second GPU, or even go with a couple of significantly larger GPUs, such as AMD's R9 295X2, there's room to spare. The case will also support E-ATX mobos, if you're looking to install something larger.

Oculus VR may only recommend a single R9 290 or GTX 970, but the other VR options may end up pushing the envelope further. If you're looking to add a second GPU in the future, however, we'd recommend stepping up to a 700W-800W modular PSU.

6 FISTFUL OF DOLLARS

SAY WHAT YOU WILL for other aspects of the case, but the P380 is a real looker. Antec uses 4mm-thick aluminium front and back panels, giving the case a distinctive look, but also jacking up the price. We think the clean front fascia with no external drive bays looks awesome, but what if you still want an optical drive? Antec includes a slim optical drive mount that sits behind the front cover. It's frankly a bit of a pain to deal with, so if you really want an optical drive you might want to look at a different case.

It's possible to swap around the USB and audio ports on the top, allowing them to face right or left (the default is left). You can also remove all the front drive cages and mount a second 240mm radiator, if you're so inclined, but that limits storage options.

1 **You can fit up to a 360mm radiator, but sometimes a simple air cooler is all you need.**

2 **The Asus GTX 970 uses a single 8-pin PCIe power cable, helping reduce connectors and clutter.**

3 **The tiny 500W Corsair PSU has long cables, a must for a case this large.**

4 **Eight 3.5/2.5-inch trays allow for ample storage, with two 5.25-inch slots up top (but with no external access).**

HI-YO, SILVER!

FOR SOMETHING AS demanding as rendering two stereoscopic images for VR, the recommended specs from Oculus aren't actually that crazy. What will be interesting to see is how game developers leverage the available hardware, and that's always been a sticking point in the console versus PC debate. By defining a relatively high recommended system, Oculus opens the doors for full DX12 support and advanced rendering features. But developers often want to up the available installation base, so they create lower-quality rendering paths. Considering the Oculus Rift shipping hardware is likely to cost at least £200, however, it's not too much to expect gamers to have commensurate hardware elsewhere.

The final Rift hardware is now shaping up, and it will include an Xbox One controller. Oculus has also revealed an Oculus Touch controller, but that will ship after the initial hardware. We have the Oculus Rift DevKit 2 (DK2), and setting it up can be really frustrating – getting the head tracking to work, in particular, was certainly more difficult than it should be. The final hardware now includes a desk-mounted sensor that we're hoping will be easier, not to mention a single cable to the headset for audio, video, data and power. The combination should help reduce the space requirements, but for a standing-up experience, you'll need a decent amount of room.

While there's a lot of potential in VR, it's a chicken-and-egg dilemma. Developers need hardware in the hands of more consumers to make money creating games. Consumers, however, want compelling software before they buy expensive hardware. And everyone wants the entire experience to be as hassle-free as possible. We're not there yet, which is why Oculus Rift isn't expected until Q1 2016.

When we consider the competing hardware and platforms, such as SteamVR, HoloLens, Project Morpheus, OSVR and Gear VR, it becomes far less clear who'll win this shootout. Oculus kick started – or Kickstarted – the current VR craze a few years back, but it isn't the only game in town. It remains to be seen whether we'll have multiple complementary platforms or a single winner-take-all solution. As exciting as virtual reality is, no one wants to get stuck owning a virtual Betamax setup.

BENCHMARKS

	TEST RIG		
Premiere Pro CS6 (sec)	2,000	1,141	(43%)
Stitch.Efx 2.0 (sec)	831	753	(10%)
ProShow Producer 5.0 (sec)	1,446	911	(37%)
x264 HD 5.0 (fps)	21.1	18.4	(-13%)
Batman: Arkham City (fps)	76	64	(-15.8%)
3DMark 11 Extreme	5,847	4,616	(-21.1%)

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100% 110%

Our current test rig consists of a hexa-core 3.2GHz Core i7-3930K 3.8GHz, 8GB of Corsair DDR3/1600, on an Asus Sabertooth X79 motherboard. We're running a GeForce GTX 690, an OCZ Vertex 3 SSD and 64-bit Windows 7 Professional.

IT'S NOT ROCKET SCIENCE

WE AIM FOR THE STARS WITH A NASA-INSPIRED, ROCKET-FUELLED, MINIATURE POWERHOUSE

LENGTH OF TIME: **1–3 HOURS**

LEVEL OF DIFFICULTY: **MEDIUM TO CHALLENGING**

THE FLIGHT PLAN

WHEN YOU'RE BUILDING a machine from scratch, compromises tend to hold you back from piecing together your perfect PC. Cost, if nothing else, is usually the limiting factor. But what if you don't have to compromise? What if, this time, you can build your dream PC? That's what we've done this issue; we've shot for the Moon. We've even themed it accordingly – going for a NASA finish that hints at the high-end components contained within.

The components you'll find in this rig are basically what we consider to be at the top of their game. We haven't completely ignored the price – you can easily spend more if you so wish – but we've tried to focus on the kit that matters. Why drop silly money on a Titan X, for example, when the GTX 980 Ti is almost its twin in most games. This is a dream machine, don't forget, so we haven't limited ourselves to just one graphics card – two GTX 980 Ti's will give you a great return for your money and will handle today's games at eye-straining resolutions and settings.

We've also overclocked the rig. High-end components tend to give you that little bit more room in the performance stakes, so it'd be remiss of us to not use the extra bit of power. And that additional push from the overclocking should just give us enough thrust to leave the atmosphere.

VEHICLE ASSEMBLY

THIS IS A NASA-INSPIRED BUILD, so we had our prototype Antec S10 case sent off to Smooth Creations to have it custom-painted to replicate a 1960s Titan II Gemini Launch Vehicle. We went with a Core i7-5930K CPU. It's two cores lighter than the 5960X, but friendlier to overclocks and your wallet – the 5960X is nearly £400 more, a hefty £200 per extra core. We got a nice stable overclock with our 5930K, bumping it to 4.5GHz from the stock 3.5GHz with the help of 1.31 volts. We kept the main engine cool with an NZXT Kraken X61.

The GPUs are a pair of EVGA GTX 980 Ti Superclocked ACXs in SLI. We overclocked these already factory-overclocked rockets further, adding 150MHz to the core clocks and 300MHz to the memory clocks using EVGA's PrecisionX software. We powered the overclock with an overvolt of 31mV. We used 16GB of 2,800MHz DDR4 memory in a kit of four 4GB modules. We ran into problems at 2,800MHz, so underclocked to 2,666MHz for stability. We probably could've overclocked the RAM a bit and reached 3,000MHz, but we didn't go looking for a RAM overclock; the timings on these modules are plenty fast.

For storage, we put the 1TB SSDs in RAID 0 for the OS, and kept the 6TB spinning drives in reserve. We mounted all of these goodies onto Gigabyte's X99 SOC Champion mobo, which has more overclocking options than we knew what to do with. We powered our ship with an 80-Plus Gold-certified Enermax 1,350W Maxrevo modular PSU.

INGREDIENTS

PART		PRICE
Case	Antec S10 Prototype Custom	£320
Motherboard	Gigabyte GA-X99-SOC Champion	£211
CPU	Intel Core i7-5930K	£410
Memory	G.Skill Ripjaws 4 Series 16GB 2800 DDR4	£120
GPU	2x EVGA GeForce GTX 980 Ti SC ACX 2.0	£1,120
PSU	Enermax Maxrevo 1,350W	£268
HDD	2x Western Digital 6TB	£420
SSD	2x Samsung 850 Pro 1TB	£720
CPU cooler	NZXT Kraken X61	£100
Fans	3x EK Vardar F4 120mm 2,200rpm fans	£51
Total		£3,740

1 BOOSTER IGNITION

THE PAIR OF 980 Ti'S that we used really push this machine into the ionosphere. The main thing to keep in mind is that they're air cooled. Maintaining good airflow was a top priority when we went into the realms of overclocking. Luckily, the SOC Champion's PCIe x16 slots are numbered (from top to bottom) 1, 4, 2, 3. That means that for the best performance, we had to put the second GPU in the third slot from the top. This gave us a nice gap where air could flow freely, in comparison to the 2–5mm it would have if the cards were in adjacent slots.

We also upped the fan speeds in PrecisionX to 90–100 per cent when we were searching for a stable overclock. To be sure, there was a lot of air flowing around these two cards. If you look closely, you'll see that spacing these cards further apart means that you can add an M.2 SSD if you prefer storage speed over a potential third GPU.

2 CRAMPED QUARTERS

SPACESHIPS AREN'T EXACTLY ROOMY. Engineers cram the most equipment into the tiniest space available to save on weight and profile. This machine was no different. When we attached the Kraken to the top mounting bracket, we had to really push the bracket into place, smashing the CPU power cables a bit. It's secured by two thumbscrews, and lining up those screw holes was a test of mettle and patience.

We could then place intake fans to the front of the main compartment to pull in lots of air for our GPUs. We could've gone with a smaller closed-loop cooler, but we wanted that performance. The X61 kept our CPU at a cool 25°C at idle, and at 57°C under a 90 per cent load, running our Premiere Pro CS6 benchmark.

3 AUXILIARY THRUSTERS

ATTACHING OUR X61 allowed us to mount three fans up front to draw in air. We chose a trio of EK's Vardar 120mm static pressure fans. These babies spin at 2,200rpm and push 131 cubic metres per hour). We hooked up the top fan to the CPU PWM fan connector (our X61 is hooked into CPU_OPT), and the bottom two to the X61's two spare connectors. It's worth noting the retail S10 has a PWM fan hub on the back of the motherboard tray, so doing things this way wouldn't be required.

For benchmarking, we cranked up the power to get air flowing over the 980 Ti's. Boy, did that air flow. Between these three fans and the two Krakens up top, we could feel the positive pressure escaping through little gaps in the doors. The S10 also features a removable filter on the outside of the main compartments, in front of the fans. A tab near the base of the S10 releases the filter for removal.

4 MANUAL IGNITION

WHEN WE WERE FIRST PLAYING with this case, we accidentally pulled the front-panel wires loose of the panel buttons and LEDs. Whoops. Luckily, this motherboard comes with a power button on the board itself. Many modern motherboards feature a power button, and they come in handy for things besides compensating for screw-ups – for example, if you're building on a test bed or want to test a particular feature without connecting the front-panel buttons.

There are also buttons to reset the BIOS to defaults, and a toggle that switches to the backup BIOS as well. That sounds trivial, but when you're using all the overclocking features this mobo has to offer, messing up is very possible. Having an easy way to switch to an alternate BIOS or reset to defaults is a good move for tinkerers and overclockers who want to push limits.

5 OPEN THE POD BAY DOORS, HAL

ONE OF THE THINGS that will first catch your eye is the S10's separate tower for hard drives. It seems excessive, but it has a real-world purpose: keeping the ambient temperature of the main compartment low. The tower's doors swing open in the front and rear of the case, making installation easy. The slots for the toolless brackets are rubberised, so drive vibration is absorbed, resulting in longer drive life and less sound from platters spinning at 7,200 RPM.

Our pair of 6TB drives were happy, kept plenty cool by a dedicated fan. The fan draws air from under the tower and pushes it up, across the surfaces of the vertically mounted drives. We hooked this fan to the SYS_FAN3 PWM fan header on our mobo, and set the speed to maximum. It stayed quiet at that speed.

6 CONTROL CONDUITS

WE DON'T OFTEN show cable management in our builds. It's not always pretty. But there's good reason to this time. The first thing to notice is how SATA power and data cables get into the hard-drive tower. A tab at the bottom of the case can be released. But this tab covers the cable pass-through, where all your SATA cables must go. We positioned the WD drives on the bottom row to stay within our cables' reach.

Also note that if you want a clean case, the rest of the system's power must snake through a fairly small cutout, requiring long PSU cables. In our build, only the ATX cable was long enough to get where it needed to go. For the CPU power, we had to route through the floor grommet into the main compartment, back out the grommet under the mobo, and then back in through the grommet above the mobo.

1 **This red LED-lit fan came with our power supply. While it uses a typical PWM fan connector, it also has a manual dial for fan speed and a switch to turn the lights on and off.**

2 **The 1,350W Maxrevo power supply gives us much more power than we need for this build. On the upside, it leaves more than enough headroom for overclocking and adding in more graphics cards.**

3 **The 2.5-inch drive cage in the PSU compartment sits right next to a fan, which helps keep SSDs (or 2.5-inch HDDs) cool.**

4 **The custom paint job by Smooth Creations really made this case a star. The retail case comes with tinted glass doors instead.**

RE-ENTRY AND SPLASHDOWN

AT £3,740, this orbital overclocker is plenty pricey, but delivers dreamy performance. This ship is essentially a tier above what we achieve in our high-end build in the feature on page 106, which includes a screen.

We had a lot of fun building into this case, which was a prototype that needed a refinement here or there. Even with minor shortcomings, the case presents well, has good airflow in all of the parts that matter, and even had room for our beefy Kraken X61 – though it meant a little pushing and shoving to get everything to align. Many of the issues we had have since been addressed and fixed in the production-line case.

When we ran our benchmarks, we really saw the kind of performance the GTX 980 Ti offers with its 6GB of VRAM. The fact that we used factory-overclocked models that we then overclocked some more paid dividends in the frame rate department.

The triple GTX 980 SLI setup in our beefy test rig was outgunned by the higher VRAM that the GTX 980 Ti's were packing. Given that a trio of reference GTX 980s cost £1,170 (at £390 each), the pair of GTX 980 Ti's, at £1,120 (£560 each), provides the greater value. Sometimes two really is greater than three.

That performance comes at the cost of power though: Reference GTX 980 Ti's draw 250 watts, or 85W more than the plain-old 980 reference cards do. Though that's still less power than the 275W the Radeon Fury X draws. The difference isn't much for this build – two 980 Ti's will put you just 5W over a trio of 980s, which draw 165W each.

The i7-5930K served us well. A hearty overclocker, it got us to a similar clockspeed as our test rig, with its 5960X, despite being short two cores. Two cores are a big deal, but with such a huge price difference, the 5930K really delivers bang for your buck.

We could have saved a lot of coin on the hard drives, if that was a motivation, since the lower-capacity WD drives are far more affordable than their 6TB brethren. Likewise, builders pay a premium for a 1TB SSD. Opting for 250GB or 500GB models could save hundreds, which could go towards a third 980 Ti, a third SSD for a three-drive RAID array or a bunch of games on Steam.

All in all, we're very happy with this build, and had a great time assembling it. While still priced at a premium, we feel this mini-rocket reaches for the stars, while not being too unattainable.

BENCHMARKS

	TEST RIG	
Stitch.Efx 2.0 (sec)	806	558
ProShow Producer 5.0 (sec)	1,472	1,163
x264 HD 5.0 (fps)	33.8	28.5 (-15.7%)
Batman: Arkham City 1440p (fps)	204	238
Tomb Raider 2160p (fps)	87.5	101.3
Shadow of Mordor 2160p (fps)	70.1	105.4
3DMark FireStrike Ultra	8,016	8,378

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

Our desktop test rig PC uses a 5960X CPU, three GTX 980s and 16GB of RAM. *Arkham City* tested at 2560 x 1440 Max settings with PhysX off. *Tomb Raider* at Ultimate settings. *Shadow of Mordor* at Max settings.

BREATHING NEW LIFE INTO AN OLD BOX

AN UPGRADE CAN GIVE YOUR AGEING PC A NEW ROUND OF USEFULNESS, EVEN WITH OLDER ARCHITECTURES

LENGTH OF TIME: **1 HOUR**

LEVEL OF DIFFICULTY: **EASY**

THE MISSION

HERE AT FUTURE TOWERS, we often build new rigs from scratch. We have the option of using just-in, bleeding-edge, nerd-porn-worthy parts, or remixing a fresh build idea from our selection of parts we've already built and reviewed. Either way, builds usually use newer-generation parts. New! Shiny!

This isn't one of those builds. We know that not everyone can, or has, the desire to go out and build a whole new PC every time. In fact, one of the best parts of building a PC is the fact that you can upgrade a system as it begins to show its age. We were digging around in the pile of parts that is the PC Format Lab, and we found a frumpy-looking gem: an LGA1155-based Core i5 budget build from 2013.

Yes, this already less-than-attractive case didn't get any prettier with time. But with a little TLC, we were able to resurrect this rig and get it a little more up to speed.

INHALE

IN OUR ORIGINAL BUILD, the PC had a quad-core i5-3350P at its heart. The CPU served the rig well against the competition two years ago, and cost £135 back then. If you can still find it, it now runs about £126. We'd mounted the CPU onto a £42 ECS H77H2-M3 mobo, which is a basic board that gets the job done. The same mobo is £30 today, though finding one won't be easy.

For memory, we'd gone with a low-profile Kingston 4GB kit of DDR3 1333. The kit was about £26 back then and is around £18 now. The Gigabyte GeForce GTX 660 OC got replaced with a more modern GTX 970 in our upgrade. The old GTX 660 cost £145 two years ago, and can be found for £157 online today.

The storage options were modest as well. The A-Data 32GB SSD, 500GB WD Caviar Blue, and Lite-On iHAS DVD+RW didn't exactly set the world on fire, and cost £30, £32 and £10, respectively. The SSD still costs about £30, while the HDD is available for a bit more, at £42. We found the iHAS for £9.

As for the Rosewill case, it's no longer available. When we got it, the basic steel case cost around £40. With a copy of Win8, the rig cost £535. Without the OS (£75), the total dropped to £460. With current pricing and without an OS, the PC would cost about £452 today. That's about the same as a decent GTX 980. As for our upgrades, we gave this little rig new wings at a cost of £507.

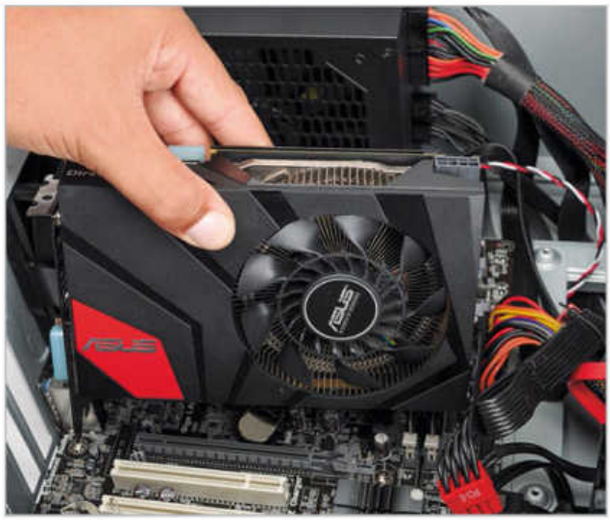
INGREDIENTS

PART		STREET PRICE
GPU	Asus GTX 970 DCMOC	£263
Memory	Patriot Viper 3 8GB DDR3 1600	£64
PSU	Rosewill Photon 650W 80 Plus Gold	£59
HDD	Seagate Barracuda 1TB	£35
SSD	Samsung 850 Evo 250GB	£76
Fan	Corsair AF140 White	£10
Total		£507

1 EYE IN THE SKY

THE GTX 970 WE UPGRADED to was by far the most expensive investment in the upgrade. At £263, this GPU is a good £100 more than a GTX 960 that has nearly the same form factor. Since we went with a 660 OC in the original build, we wanted to put in a card that had clear performance gains, but wouldn't let the modest Core i5 hold it back. Even though we regularly build with GTX 980s and above, the GTX 970 is still a very capable graphics card for 1080p gaming.

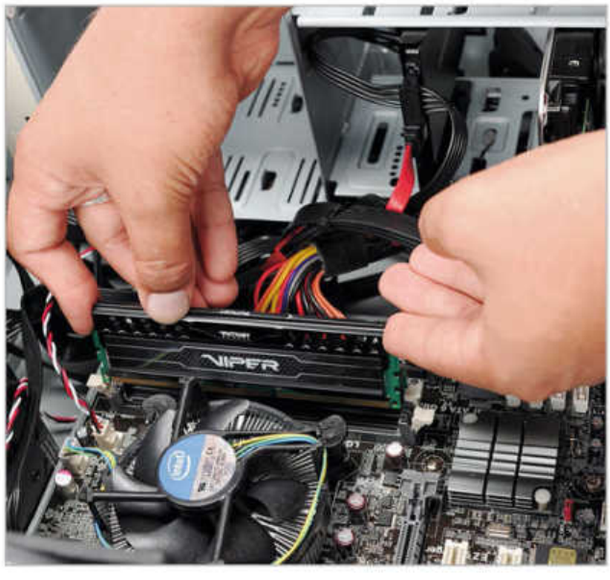
The GTX 970's modest TDP of 145W meant that we didn't have to go crazy with our power supply, either. The card only takes a single 8-pin power connector, which is nice considering the lack of cable management options in the case.



2 A LITTLE MORE LIFT

WE KNOW THAT it could be argued that 4GB of memory is plenty for a budget rig, but we really feel that 8GB makes the OS and any games feel a lot more comfortable. After all, there's a good chance you won't be gaming all the time. Browsers, photo editors and audio applications all get memory-hungry. Eight gigabytes should be enough to satiate them in pretty much most circumstances.

These two 4GB 1,600MHz sticks of Patriot's Viper 3 line were taken from a four-stick 16GB kit we had on hand here. While that kit is a bit more pricey, we looked up the 8GB kit and found it to be around £65. That's not too far off course as far as RAM prices go, so we didn't hesitate to use these two modules. Another thing to notice is that this mobo only has two DIMM slots, so more RAM would require DIMMs with higher capacity. That costs money, another reason to keep it at 8GB.



3 INCREASED LUNG CAPACITY

IF THERE'S ONE THING we wanted to upgrade, it was the SSD. Solid-state media has got much cheaper, so we thought it would be reasonable to put money into a higher-capacity and -performance SSD. While the Samsung 850 Evo won't blow your hair back, it's still very speedy. At 250GB, we thought it well worth the £76. For that money, you can have your OS, Steam library and a good number of apps all on one drive.

We left in the original 500GB WD Caviar Blue and added in a 1TB Seagate Barracuda. Hard drives can and will fail. Using the Barracuda as a backup for the WD is reasonable. On the flip side, hard drives tend to have a lifespan of about five years. Since this rig is two years old, we could also use the Barracuda as primary storage and the WD as backup for three more years. This should minimise writes and extend the drive's life a little more.

4 INTO THIN AIR

WHEN WAS THE LAST TIME you saw a case that mounted the power supply up top? For us, it's been quite a while. With few exceptions, modern cases place PSUs on the bottom. There are plenty of reasons for this: to make way for exhaust fans and cooling radiators, to help dissipate heat more effectively and because installing a heavy PSU above a bunch of pricey components is an unnecessary risk.

We'd used a cheapo PSU that came with the case. We decided to replace it with a 650W unit from Rosewill. The PSU is 80 Plus Gold certified, which means that it will actually use more of the power it draws from the wall, not just dissipate it as spare heat. The unit also comes with a five-year warranty, which means that by the time you upgrade the CPU and motherboard in this rig, it will probably still have plenty of life left in it.

5 THE JET STREAM

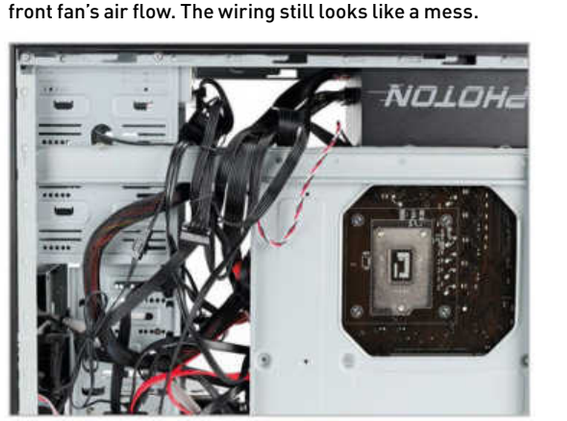
ONE THING WE NOTICED was the lack of a front fan. With the original configuration, heat wasn't a big issue. And, to be fair, the rear fan has a healthy airflow rate. However, we felt that with an extra HDD and a stock CPU heatsink and fan, a little extra air couldn't hurt.

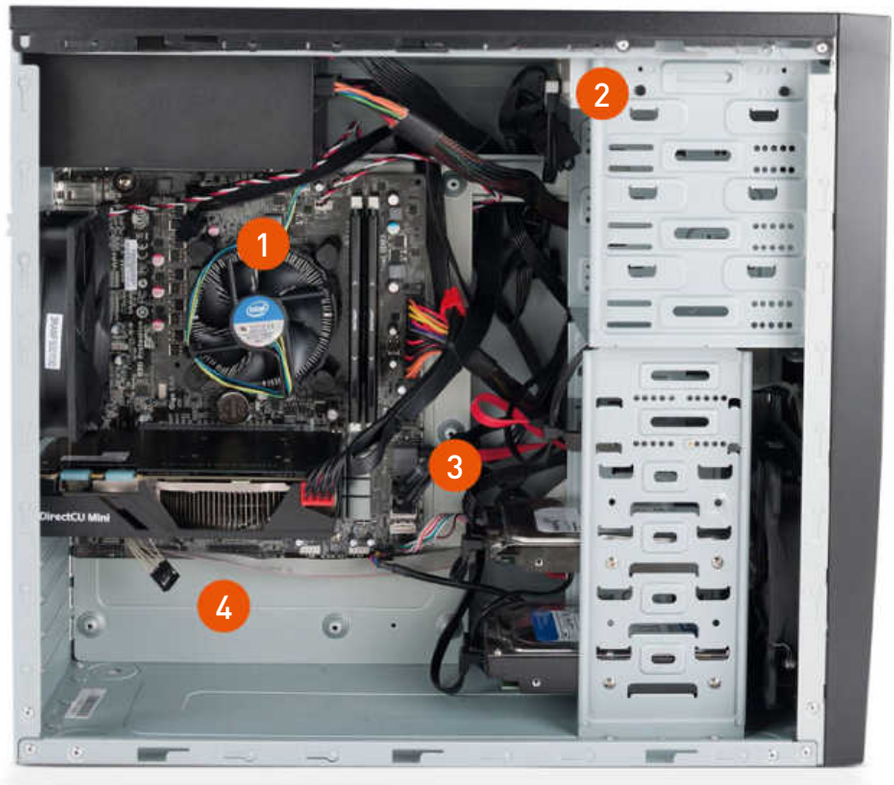
To install the 140mm Corsair case fan, we had to pry off the plastic front panel. From there, we were able to use case fan screws to attach the white LED fan. Easy enough. What we didn't anticipate was the lack of an extra PWM fan connector on the mobo. The H77H2-M3 only has two PWM pinouts: one for the CPU fan, one for a case fan. Lucky for us, the SATA power cables for this PSU have Molex connectors on their ends. We found a Molex-to-PWM connector and plugged it into one of the SATA cables without a problem.

6 GASP!

IMMEDIATELY OBVIOUS with this case was the utter lack of cable management. In terms of PC cabling, we like our builds to be as organised as possible, but this is the stuff of nightmares. What seems like an obvious route for cables – over the horizontal rail and behind the drive bays – is made impossible by a side panel that has an inward (inward!) bevel. When we tried to keep cabling tucked behind the mobo tray, we felt like the case was making fun of us. "Oh, that's cute," it would say. "I bet you'd just love an extra centimetre. Tough luck, hotshot."

Coupled with the woefully insufficient zip ties that came with the PSU, this cable job could have you waking up in cold sweats. We had to stuff the cables behind the drive cage, doing our best to keep them out of the way of the front fan's air flow. The wiring still looks like a mess.





1 **We didn't bother adding an aftermarket cooler for this Core i5-3350P. The locked CPU doesn't allow for overclocks and is plenty cool, as-is.**

2 **We didn't go with a Blu-ray and instead stuck with a basic DVD+RW. We popped in a basic Plextor model because, when we found this box, the original drive was missing.**

3 **Only two of the six SATA cables have horizontal ports, which excluded longer GPUs from being used on this mobo. Luckily, our GTX 970 is pretty short.**

4 **The long grey ribbon cable is for the front panel audio. We had to make sure we disconnected this before removing the panel to prevent bent pins.**

EXHALE

WHEN WE SET OUT on this project, we specifically wanted to revisit an older build. Sometimes, upgrading an old PC can feel like hooking up with an old friend you've lost contact with. Some things carry over from the past, but new additions make it different.

However, this wasn't a single cheap upgrade. The total cost of parts we used in the upgrade almost exceeded the original cost of the PC. That said, upgrading the CPU and motherboard would have added another several hundred pounds. By holding on to a slightly older mobo and CPU, we still got a respectable PC for less than the price of a new one. That's not bad, if budget is an issue.

And speaking of budget, these upgrades are totally do-able as incremental upgrades over time. Adding a fan, storage and RAM is relatively cheap and easy to do. The graphics is more expensive to modernise, especially since the PSU upgrade is a good idea for the new GPU. But as time goes by, upgrading the case, motherboard and CPU are certainly possible upgrades that could make this PC more current.

This rig really chugged along in our timed benchmarks. It took half an hour for it to finish the ProShow export, and almost 20 minutes to finish stitching photos. Even though it had four cores, the modest CPU crunched numbers at a pokey 10.3 frames per second in our X.264 benchmark. In our graphics benchmarks, the GTX 970 made a respectable showing. In 3DMark FireStrike Ultra, this build beat another budget build we have, costing about £640, which sports a GTX 960 and i5-4590. It scored about 700 points lower than a £1,200 mainstream build of ours that boasts a i7-4790K and GTX 980.

That midrange PC's CPU and GPU combo alone costs £657 – more than all the combined upgrades that went into this build, not to mention that its CPU is also sitting on a more expensive Z97 board (£142). All things considered, these upgrades provide a marked improvement in performance at a reasonable price.

As for the game benchmarks, *Batman: Arkham City* showed an enjoyably playable 70fps at 1440p, which lets us know that other games will fare well at 1080p, even at higher settings. The GTX 970 couldn't really keep up when it came to 4K gaming, as both *Tomb Raider* and *Middle-earth: Shadow of Mordor* were barely smooth at 28.6fps and 30.6fps, respectively, at 2160p.

BENCHMARKS

	TEST RIG	
Stitch.Efx 2.0 (sec)	806	1,165 (-44.5%)
ProShow Producer 5.0 (sec)	1,472	1,805 (-22.6%)
x264 HD 5.0 (fps)	33.8	10.3 (-69.5%)
Batman: Arkham City 1440p (fps)	204	70 (-65.7%)
Tomb Raider 2160p (fps)	87.5	28.6 (-67.3%)
Shadow of Mordor 2160p (fps)	70.1	30.6 (-56.3%)
3DMark FireStrike Ultra	8,016	2,484 (-69.0%)

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

Our test rig PC uses a 5960X CPU, three GTX 980s and 16GB of RAM. *Arkham City* tested at 2560 x 1440 Max settings with PhysX off; *Tomb Raider* tested at Ultimate settings; *Shadow of Mordor* at Max settings.

CAGED POWER: ALL ON DISPLAY

IF YOU'VE SPENT LOADS OF CASH ON COOL COMPONENTS, WHY HIDE THEM AWAY IN AN ENCLOSED CASE?

LENGTH OF TIME: **2 HOURS**

LEVEL OF DIFFICULTY: **MEDIUM**

ASSEMBLING THE CAGE

2015 WAS A GOOD YEAR for new PC products, and we thought that including some of them here would be more than appropriate. It also helped that Max, from our video team, wanted to build a new rig into an open-air case by In Win that he'd bought. So we figured: Why not?

Most of the time, our builds end up in PC cases that enclose the guts on all six sides. Even if there is a side panel window, five out of six sides remain mostly or totally opaque. That means that the case is on display, not the parts inside. Seeing as the case costs only a fraction of the price of the PC, it's a shame to hide all those parts away behind sheets of black steel and aluminum.

We wanted to try out this open-air case because it gives us a chance to look at those parts that are too often hidden away. But with beauty comes pain. An open-air case like this one presented some unique challenges for our build.

Even with those challenges, we were happy with the final result, and hope that Max isn't too upset when we have to take back some of the parts and keep them in our lab. Sorry, Max.

ROUNDING UP THE PARTS

WHEN WE SET OUT to do this build, we wanted to include some shiny, new parts. This, of course, meant we had to go with Skylake; we've been overdue for a build that used Intel's latest architecture. For graphics, though, we had a choice: We could go lower-end with the recently released GTX 950, or go bigger with the AMD's R9 Nano.

Guess which way we went. More power is sexier, so we chose the Nano, which fitted well in this mini-ITX build. The CPU and GPU found a home on the Gigabyte GA-Z170N motherboard, which supports DDR4 and offers wireless networking too, with its mini-PCIe Wi-Fi card. We had an EVGA Z170 board, but the included Wi-Fi was a good reason to pick this board over the other. We just wish that the mobo came with on-board power and reset buttons, like the EVGA model. As this is a Z170 board, we had to go with DDR4 memory. We got a couple of 8GB sticks of 2,666MHz Corsair Dominator.

All of our parts found a comfy, airy home in the In Win D-Frame Mini. While Max chose the orange and blue frame, it also comes in black and red. The cool thing about it is that there's no clear top or bottom; you only need to worry about access to ports and buttons.

The 750W power supply is plenty for the parts we chose, and as mini-ITX is limited to one GPU, there's no need to worry about extra headroom for SLI or Crossfire. However, the extra wattage does allow for single-GPU upgrades, or the addition of spinning drives.

INGREDIENTS

PART		STREET PRICE
Case	In Win D-Frame Mini (orange)	£165
Motherboard	Gigabyte GA-Z170N	£109
CPU	Intel Core i7-6700K	£236
Memory	16GB (2x 8GB) Corsair Dominator Platinum DDR4 2666	£112
GPU	AMD Radeon R9 Nano	£427
PSU	BitFenix Fury 750G 80 Plus Gold	£80
SSD	Samsung 850 EVO 2TB	£525
CPU Cooler	Deepcool Maelstrom 240	£116
Total		£1770

1 HOT STUFF

THE RADEON R9 NANO is quite a powerful GPU, given its tiny form factor. However, we noticed that it got pretty toasty when we ran our graphics benchmarks. While normal closed cases could solve this by channeling air through the case, we were low on options because there was no way to effectively push extra air over the card. The air coming from our CPU radiator was nice and cool, but the slight offset of the motherboard meant that the Nano wouldn't get any of the cool breezes. Placing the "front" glass panel on the case helped a little bit, but the Nano breathes best with a little extra air flow from a case fan.

If we were to redesign the case, we'd like to see an extra removable bracket for a case fan, just below the GPU mount. This would better support the use of extra-toasty GPUs, which would usually have more forced air, to stay a little cooler under load.

2 SIDE MOUNTED

THE PSU is the heaviest component in nearly any build, so mounting it on the side of the case might seem counter-intuitive. Not so, with the D-Frame. The PSU happily occupies a bracket on the side of the cage, but doesn't make the cage feel off-balance.

To make things neater, we went with individually sheathed cables, which are easier to manipulate. Routing the cables was a bit tricky with a smooth aluminum plate, instead of a motherboard tray rife with cable-management tie loops. Luckily, the cage came with a few accessories that helped.

We used a modular power supply, so there's no need to stash unused cables. That's a big deal in a case where there are no hiding places for your cabling.

3 USB 3.0 WOES

IF THERE WAS ONE BEEF we had with this motherboard, it was the positioning of the USB 3.0 front panel connection. After you figure in the presence of a GPU, it became clear that there was no sexy, clean way to attach the cable.

To the left, you have the R9 Nano, and routing under the GPU between the PCIe slot and the "back" panel was too tight a squeeze. If we came from below, the cable would have routed across the memory and CPU. We decided to run the cable over the "top," which places it over a pair of USB ports and the Wi-Fi antenna connectors. The result was the best of a bunch of less-than-ideal options. If there's an upside, it's that the USB cable is braided, which makes it at least look good, even if it is in the way. Then again, some may like the appearance of cables jutting out of the mobo, giving it a cybernetic look. We won't judge.

4 SILENT STORAGE

WITH THE RECENT RELEASE of the 2TB Samsung 850 EVO, we thought it would be perfect for a mini-ITX build. Having two whole terabytes available on an SSD is pricey, but it has its advantages: It eliminates the need for a small HDD for Steam games or media files, and there's one less moving part to fail from frequent moves to and from LAN parties or events.

It's easy to forget that an enclosed case muffles the sound of fans, and hard drives searching for, reading, and writing data. The high-speed clicks of the hard drive disappear when using an SSD, leaving only the CPU cooler and GPU as noise sources.

The black finish on the 850 EVO is similar to the finish of the aluminum mount of the D-Frame, which makes the slim SSD seem to disappear. The downside is that the drive is a little too far from the edge of the plate (two or three millimeters), which made it a bit hairy when we tried using an L-shaped SATA cable.

5 DOMINATING THE CAGE

WHEN WE LOOKED for memory, we wanted to go big on capacity but we noticed that most of our DDR4 kits are 16GB, but in 4x 4GB kits. Bummer. As we searched, we remembered: We had a machine that could donate a few sticks. We grabbed two 8GB sticks of Corsair Dominator RAM from our 2015 Dream Machine, and used them.

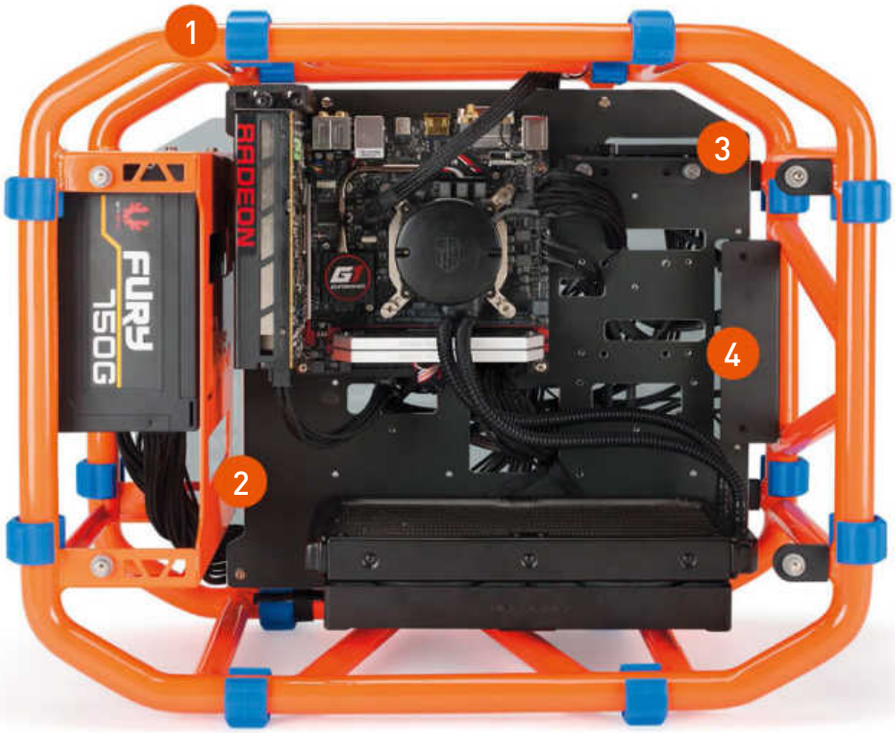
As with most X99 systems, our Z170 board from Gigabyte defaulted to setting the RAM clocks of the 2,666MHz sticks at 2,133MHz. The problem was solved by upping the multiplier for the RAM clock. Leaving it at 2,133MHz wouldn't have hurt performance much, as RAM clocks are rarely a bottleneck now. In other mini-ITX builds, going with 2,133MHz DDR4 RAM would be fine in most cases, and you'll save a little coin by forgoing higher RAM clocks.

6 ONE COOL CAGE

ONE OF THE NEAT THINGS about this build was the way the cage accommodated our cooling solution. It comes with a bracket for a 240mm closed-loop cooler, which sits out of the way at the "bottom" of the cage. We were able to get our Deepcool Maelstrom 240 snugly in the bracket, with nary a screw to secure it in place. Other coolers might not stay put with friction alone, so the eight screw holes can be used.

The Deepcool chiller was our backup choice, though. We tried using a bigger cooler, but for some reason it wouldn't have good enough contact with our CPU, which resulted in some problems booting.

The main gripe we had using a 240mm cooler with this mobo was the lack of PWN pinouts. There's no CPU_OPT or second case fan pinout, meaning we had to do something to get three PWM connectors fit on two pinouts.



1 **The blue rubber bumpers on the D-Frame Mini enable you to position the cage in any orientation you like. They also stop the case from sliding around in your car's trunk on the way to a LAN party.**

2 **The extra room below the PCIe slot allows for full-length video cards. In our build, the Nano leaves this area sparse and clear.**

3 **Thumb screws allow for the attachment and removal of hard drive and cooler brackets, for tons of modularity.**

4 **The "front panel" is a bit of a misnomer in this cage, where there is no clear front, back, up, or down.**

BREAKING OUT

THROWING ALL OF THESE PARTS together in a cage was a lot of fun and was quite a different building experience. Such a build requires you to think more about the aesthetics of the build's entirety, since there's no hiding of cables or extraneous accessories here.

Like we said, though, an open-air case build is not without its challenges. One of those was the cooling system. We started off with a larger cooler that ended up not maintaining good contact with our CPU for some reason, so we had to go with the Deepcool we had on standby. Once we had the radiator and pump in place, we had three PWM connectors to plug in, but only two pinouts to work with.

We solved this in a roundabout way. First, we plugged the two fans for the radiator into the CPU and case fan pinouts. We then connected the pump to a two-pin Molex-to-PWM adapter. This had two consequences, which we weren't fond of. First, the two fans ran at different speeds, since each PWM pinout runs as a function of a different temperature sensor. The CPU fan is a function of CPU temps, as you'd expect, but the case fan takes temps from the motherboard itself. While we stayed at acceptably cool temperatures due to the large radiator, we wouldn't do this when overclocking, as the fan plugged into the case fan connector wouldn't rev up as temperatures increase. Not good.

The other side effect was that the water pump runs at full speed while connected to the two-pin adapter. Normally, you'd connect the pump to a four-pin pinout for the same reason you'd attach the radiator fans to them. However, we needed the pump to work, so we put up with this while we ran our benchmarks.

Our caged rig did pretty well in some aspects, while relatively poorly in others. In the single-threaded CPU benchmarks, the i7-6700K Skylake performed well, outpacing the i7-5960X in our zero-point. With a 240mm cooling setup, we believe this CPU could score even higher with overclocking. When we reviewed the CPU, the 6700K got a 17 percent boost from overclocking. Not bad at all.

When it came to the 3D application benchmarks, the little R9 Nano put up a good fight. Considering our beefy zero-point machine has three GTX 980s in SLI, a single GPU can hardly expect to beat it.

Despite having less than half the 3DMark score in Fire Strike Ultra, the Nano delivered playable frame rates in *Tomb Raider* and *Shadow of Mordor* at 4K. In *Batman: Arkham City* at 1440p, the 92fps means that there's plenty of power there to keep a FreeSync 1440p monitor synced and happy at 60Hz.

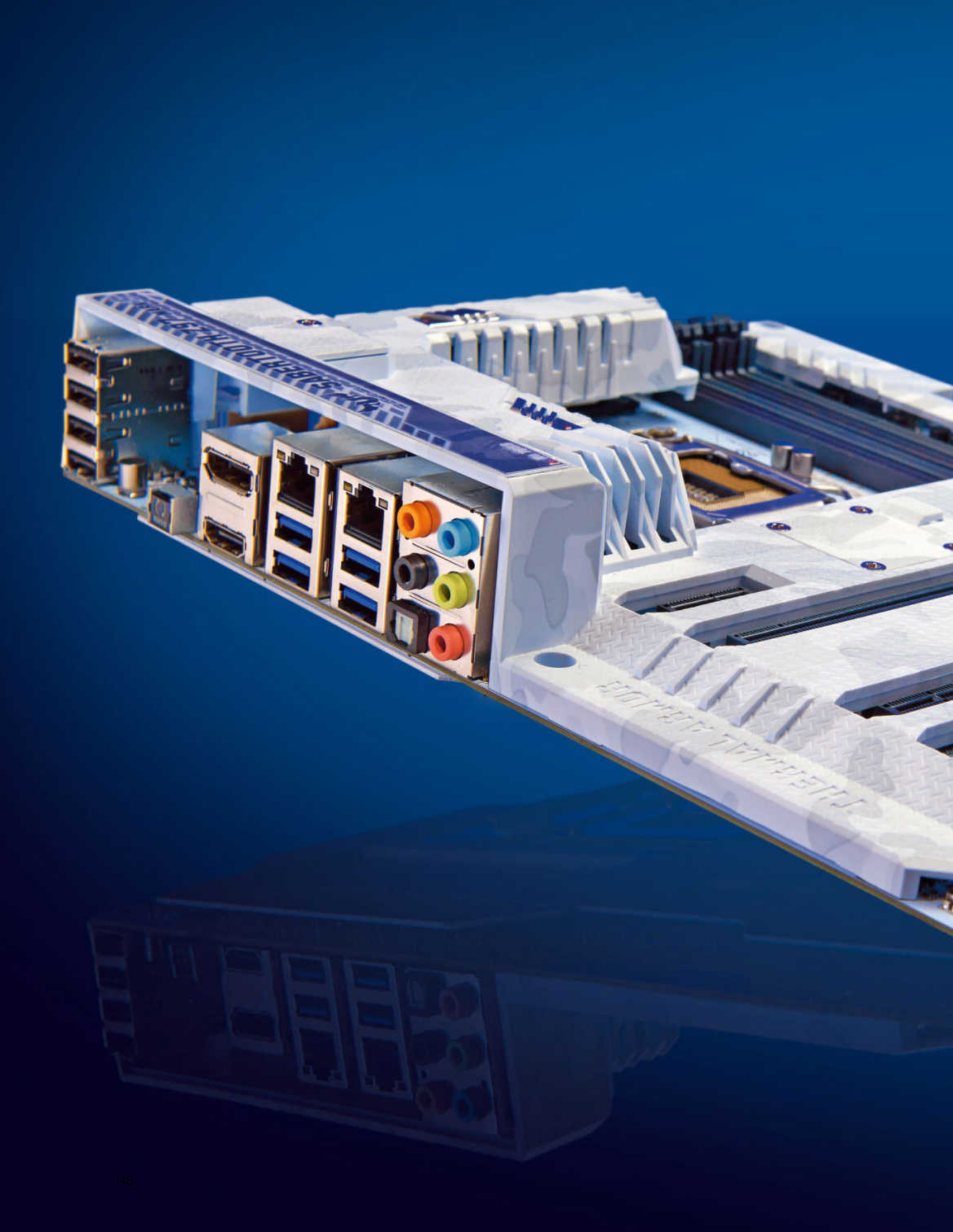
In the multithreaded test, x.264, the octa-core 5960X still reigns supreme, but for most gamers and enthusiasts who don't encode video all day, this build would perform nicely. And with its portable, unique form factor, it can be quite the conversation starter.

BENCHMARKS

	ZERO-POINT	
Stitch.Efx 2.0 (sec)	806	781 (3.1%)
ProShow Producer 5.0 (sec)	1,472	1,442 (2.0%)
x264 HD 5.0 (fps)	33.8	19.54 (-42.9%)
Batman: Arkham City 1440p (fps)	204	92 (-54.9%)
Tomb Raider 2160p (fps)	87.5	36.6 (-58.2%)
Shadow of Mordor 2160p (fps)	70.1	40.2 (-42.7%)
3DMark FireStrike Ultra	8,016	3,362 (-58.1%)

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

Our desktop zero-point PC uses a 5960X CPU, three GTX 980s, and 16GB of RAM. *Arkham City* tested at 2560x1440 max settings with PhysX off. *Tomb Raider* at Ultimate settings. *Shadow of Mordor* at Max settings.



THE ULTIMATE
PC Building

TOP TIPS

GET MORE FROM YOUR KIT AND MAKE SURE IT'S PERFORMING

FREE SPEED!

OVERCLOCKING MASTERCLASS

The hardware, software and know-how you need to get the most from your PC

Overclocking. It's long been a part of a PC enthusiast's toolkit when it comes to wringing every last ounce of power from our beloved machines. Whether you've opted to run AMD or Intel, overclocking has been a staple food group of the techie's diet for as long as there's been chips in PCs. The basic principle is simple: Add more voltage to the component part, provide it with sufficient cooling, either through water or air (or Ln2 for the more adventurous among us), and increase the Hz output of the hardware you're trying to improve.

But this doesn't come without risk. While we've come a long way in the world of overclocking, it is still possible to fry your CPU, GPU, RAM or motherboard to the point where it's more charred than your old man's best barbecued sausages. So, the first question you should always be asking yourself is whether it's worth the risk. The answer, generally (and, ahem, unhelpfully), is sort of.

As proven time and again by Intel's latest and greatest chips, a good quality CPU core often outstrips an increase in gigahertz. On the flip side, however, increasing the performance of a two-year-old core so that it can keep pace with the newer generation can save yourself a pretty penny, and possibly put off that upgrade for another year or more. So read on for step-by-step guides to overclocking your CPU, RAM and GPU.


Z97
intel
gigabit
ethernet
ATX12V
CORSAIR

OVERCLOCKING YOUR CPU

Learn to fulfil your processor's potential in 10 simple steps

Before crossing the start line, there's a few basic principles to get your head around. The first one is heat. Inevitably, the more voltage you add to your components, the more heat that component is going to output. Second, the higher the clockspeed you're trying to achieve, the more voltage you will need to power that attempt. And thirdly, there's only so much voltage your PC part can take before you start to see detrimental effects. These could be a drop in frame rates for GPUs, corrupting processes on the CPU, or even a failure to boot at all. These, essentially, are the basic limits of overclocking.

All chips are born equal, but some are more equal than others. You'll often hear overclockers talk of 'The Silicon Lottery'. In short, this is to do with the manufacturing process with each and every processor. Small imperfections in the application of the silicon lead to a variance in how well the chips perform, both in stability with an increase in voltage, and how much heat they produce at max load. You might get lucky with yours, or you might not. It can equate from anywhere between 0.2GHz difference to, in some cases, up to 1GHz in overclocking potential.

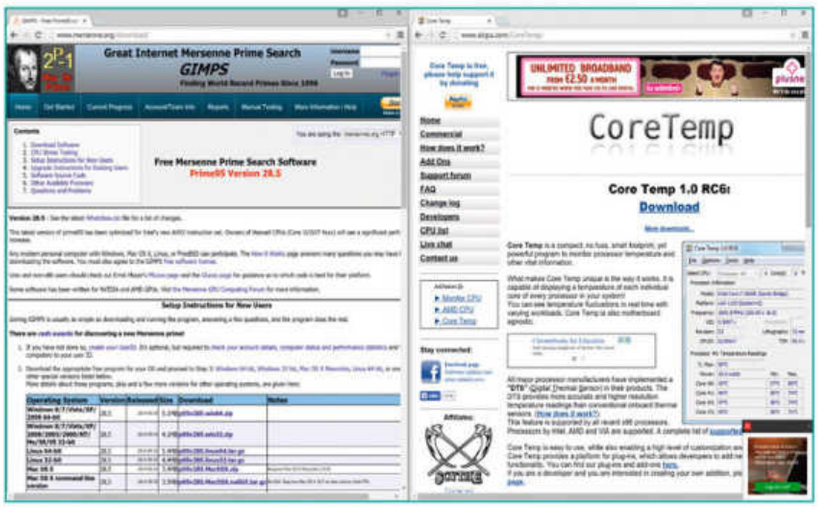
So, assuming you've got an aftermarket cooler of some description (see "Picking a Cooler", right), that you have a processor or component that's capable of overclocking (K/X series for Intel and any AMD chip), and that you understand how to get into your BIOS, here's how to get going.

1 CHECKING CPU STABILITY

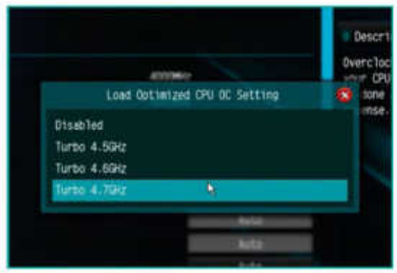
To ensure a successful overclock, we'll need to know that the CPU is stable at both idle and max load. To do this, we'll be using a free piece of software called Prime95, from http://bit.ly/1kVNJZh. You'll also want to download a program to accurately monitor the temperatures your CPU is outputting. For this we'll use Core Temp, from www.alcpu.com/CoreTemp/, as this works with both AMD and Intel cores. There are alternatives out there – Corsair and NZXT have proprietary software that works with their AIOs, plus most motherboards have viewable temperature controls that you can use from the desktop. If you don't fancy installing anything on your rig, then Real Temp GT is your guy.

2 CORE TEMP

Once those programs are extracted or installed, load Core Temp to begin monitoring your CPU's temperature. Always look at the lowest core temp to give yourself a good understanding of how hot your CPU is running.



Prime95 is a key overclocking tool, with its stress tests being a major part of the process.



Default profiles limit potential, but are often safer than manually entering them.

3 STRESS TESTS

Now we'll want to benchmark your CPU, at stock, to see how hot it runs at 100 per cent. Start Prime95, select 'Just stress testing', and then you'll be given a list of options as to which stress test you'd like to perform. Choose 'Blend Test' and press 'OK'.

4 INTO THE BIOS

After about 5-10 minutes, once your temperatures have stabilised, go into Prime95. Select 'Test' on the top bar and hit 'Stop', then restart your PC and mash that [Delete] key to get into your BIOS. In this test we're using an ASRock Z97 Extreme 4 motherboard, so the UEFI could be a little different in comparison to some of the other manufacturers you'll find out there, but the base settings will essentially be the same.

5 AUTO-OVERCLOCK

Once inside your BIOS, find the overclocking tab. In ours it's named 'OC Tweaker'. Once in, you have several options. The easiest way to overclock your CPU is to let the motherboard do the majority of the work. Most manufacturers will include overclock profiles, usually ranging from 4GHz to 4.8GHz, depending on the CPU installed.

Setting the motherboard to run one of these profiles will allow it to attempt to overclock the chip to that frequency without any user input. This can be a quick solution, especially if you're only dialling in a conservative overclock (3.5GHz to 4GHz, for example), but this isn't conducive if you want to push beyond that 4.8GHz barrier, or if you can't reach that frequency through the automated profiles.

6 CHANGING THE MULTIPLIER

More adept users will find manual control a lot more comprehensive in regards to what true overclocking is all about. To keep it simple, you want to be changing the CPU ratio, or multiplier, for all cores to the target number you wish to achieve. That's 35 in this case. The multiplier then works with the cores' BCLK frequency (usually 100) to create that final figure of 3.5GHz. In this tutorial, we're going to attempt to overclock our CPU just to start with from 3.5 to 4GHz, simply by changing the multiplier.

This looks like it'll be stable.

7 TEST AT MAX LOAD

Once you've changed the CPU ratio multiplier to 40, save changes and exit the BIOS. Boot into Windows, open Core Temp to monitor your CPU temp, then open Prime95 and select 'Options', 'Torture Test' and finally 'Blends Test', to see how your chip fairs at max load. If it's stable for at least five minutes, we can begin to up the multiplier to achieve a higher overclock.

8 FINDING THE LIMIT

At this point, you'll want to increase the multiplier by one and repeat the process of stress testing in Windows each time, until you reach the point where you initially either blue screen or your CPU begins to thermally throttle itself. Ideally, you want to blue screen before you reach your thermal limit.

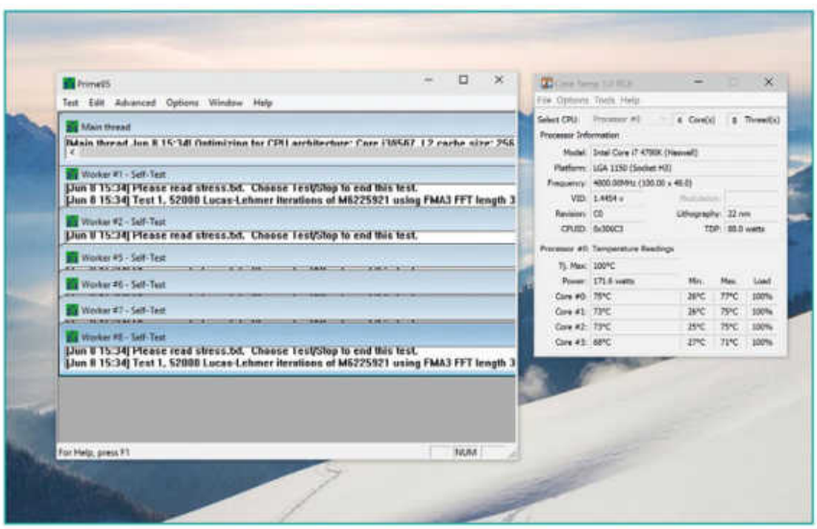
9 INCREASING THE VOLTAGE

To overcome the blue screen issue, we need to start working with the Vcore voltage. Back in the BIOS you want to find CPU Vcore Voltage Mode. Change this to 'Fixed'. At this point you may need to do some research as to what the stock Vcore your CPU takes, and what people are suggesting for overclocking. You'll want to begin increasing the voltage by 0.01 volts each time, until you can successfully boot, stress test and maintain stability at your target frequency. Once you get a little more comfortable overclocking, you'll find yourself increasing voltages by 0.05 or 0.1 at a time. It's more about learning how your CPU responds to different amounts of voltage at this point.

Eventually, you'll reach a point where you cannot reach that next frequency, regardless of how much voltage you throw at it. This is when you want to dial back your overclock by 0.1GHz and drop the Vcore voltage back to the last stable settings for that frequency and maintain it there, as this is your final overclock.

10 BACK TO BENCHMARKING

To ensure a stable overclock, you should now benchmark for as long as you feel is appropriate. This can be anywhere from an hour to a full day, depending on how patient you are.



Always stress test your CPU before overclocking, to get a good reference point.

PICKING A COOLER

The first thing to consider after you've decided on overclocking is what you'll use to cool your components. To put it bluntly, the stock coolers that AMD and Intel provide simply won't cut it when it comes to dissipating the excess heat that comes from adding more voltage. They're designed to deal with what the processor can output at stock frequencies, and not a lot more.

AIR

The more traditional, easier solution would be to rely on air cooling for your CPU. There's a huge list of air coolers out there, from a wide variety of brands, but it's vital that you consider the size of the cooler versus the height of your RAM and the size of your case. The last thing you want is to buy a new heatsink for your shiny new i7-4790K, only to discover it won't fit over the top of your Corsair Dominator GTs. The Dark Rock Pro 3 is a particular favourite of ours – it's silent, yet can effectively relieve your CPU of over 250W of TDP, plus it'll keep your bacon cool.

AIO WATER COOLING

The second option, and one we all prefer here at Future Towers, is an all-in-one water cooling loop. You've probably seen a lot of these kicking about – Corsair's Hydro H100i being the more famous of the bunch. These are a quick and easy solution, and often provide a great deal more cooling than a single air cooler, due to their increased surface area. They're also a lot less finicky to install (providing you have the radiator support), and can clean up your rig quite nicely while allowing you to swap out components with relative ease.

CUSTOM-LOOP COOLING

Finally, the elephant in the room, the fully custom loop. It's the dream, the crème de la crème, and the aspiration of every tech enthusiast starting out on the bumpy road to a successful overclock. It's also something that's become increasingly easy to build in recent years. Although certainly the most effective of the three, due to the ability to expand on your loop by adding more radiators, and cool more components, it can become very rigid, especially if you want to change out a graphics card, for example. It's definitely something that needs to be researched fully before committing to, if only because it can easily add £400 to your costs. And that's with the cheapest components out there. But wow, does it look good when you're done. The Parvum Titanfall rig is a prime example of this.

OVERCLOCKING YOUR RAM

Wait! There's more! Overclocking isn't limited to just your processor

Pushing your CPU and RAM to the max.

Yes. It's true. Overclocking doesn't just mean tinkering with your CPU. Other avenues exist if you're keen to shove the boat out a little bit more.

RAM speeds over the course of the last few years have almost tripled in frequency, meaning performance can be improved quite dramatically in certain computational programs. It's important to bear in mind, however, that the higher you push your RAM frequency, the more your CPU will suffer. In other words, it might mean an overall lower final overclock for your little powerhouse.

On the other hand, AMD's APUs, despite being a lower-end graphics solution, will benefit hugely from an increase in those same frequencies. So, what does all this come down to?

1 WHAT'S THE FREQUENCY?

Identifying the frequency of your RAM on purchase is crucial. We wouldn't go for anything less than 1,600MHz as a minimum if building a rig today. With Skylake and DDR4 around the corner, we'd be tempted to hold off a little and wait for that, as the price of the next generation of memory is still continuing to plummet.

2 THE PROFILE SETUP

We're using a pair of Corsair Dominator Platinums, clocked at a stock speed of 2,133MHz. To take advantage of any potential additional clockspeed, you'll need to set up the memory with the correct profile on install. So, either Intel's XMP profiles or AMD's AMP profiles. This is exactly what we'll be using, just to do a slight overclock of the memory.

3 UPPING THE FREQUENCY

Enter your BIOS by again headbutting the [Delete] key. Make sure you have either your XMP profile or your AMP profile selected, then change the memory frequency to one frequency higher than your memory's stock frequency. In all likelihood, your RAM should be able to manage and maintain that frequency, regardless of what the stock speeds say.

4 ABOVE AND BEYOND

If you want to take it further, this time we'll change the BCLK frequency, instead of adjusting a RAM multiplier. You can up this in very small increments. But it also ups your CPU's basic overclock, so if you've already OCed your chip to the absolute max, it's unlikely you'll be able to push the memory or the CPU any further.

OVERCLOCKING YOUR GPU

Last, but certainly not least, the final hurrah of overclocking

Afterburner's in-game overlay makes it easy to monitor how your GPU is doing.

With DirectX 11, at least, OCing the GPU is the area of most benefit to gamers. But it's also where overclocking has most dramatically changed. That's because, with Nvidia's GPU Boost and AMD's Power Tune, it's no longer possible to simply up the voltage and in turn increase cards' core clockspeeds.

It's now often better to ignore the voltage and let the proprietary software do its own thing. This way you can avoid reaching the artificial power limits set by our GPU overlords – cores won't throttle themselves in an attempt to control imaginary temperatures, that may or may not be present, even if they're running on an aftermarket cooler, or water. Sounds ridiculous, right? You're not wrong. Still, we'll show you how far you can go with these cards.

1 GET THE SOFTWARE

Unlike CPU overclocking, we need to download some proprietary software to use within Windows. It's usually most beneficial to download whichever manufacturer's software your card's PCB is based upon. GPU Tweak for Asus, Afterburner for MSI, and so on. In this case, we're using a reference cooler on our GTX 980, so we're using MSI's Afterburner. It provides frame monitoring for benchmarking, a customisable display and in-game overlays to monitor how the cards perform compared to their stock speeds.

2 ENABLE MONITORING

Once Afterburner is installed, the first thing we want to do is enable in-game overlay, and frame rate monitoring, followed by (for us at least) changing the skin to something a little more workable.

3 TEST STOCK SPEEDS

Next you'll want to get a clear understanding of how your card performs at stock speeds. We're using *Total War: Rome II*'s benchmarking software at max settings at 2560 x 1440. We achieved a minimum frame rate of 19, a max of 61, and more importantly an average of 44.7.

4 INCREASE THE POWER LIMIT

We now need to get into the overclocking side of things. Head back to desktop and open up MSI Afterburner again. The first thing we're going to increase is the power limit. Move the slider to as high as it will go. This should allow our card to use absolutely every inch of power we can get, beyond Nvidia's recommended stock settings, meaning the card can run all the way up to 91 degrees Celsius, as opposed to the stock 79°C.

CPU BENCHMARKS

	Core i5-4670K Turbo to 3.8GHz	Core i5-4670K OC to 4.5GHz	Core i7-4790K Turbo to 4.4GHz	Core i7-4790K OC to 4.8GHz
Idle temp (°C)	29	29	27	31
Load temp (°C)	71	84	62	70
Cinebench	566	667	877	943
Total War: Rome II (min/avg/max fps)	19/40/59	16/40/53	16/42/58	17/42/57
Vcore	N/A	1.385	N/A	1.445

Tests carried out on max settings/shader model 4.1/1440p.

GPU BENCHMARKS

	Stockclocked GTX 980	Overclocked GTX 980
Total War: Rome II Minimum fps	17	17
Total War: Rome II Average fps	45	54
Total War: Rome II Maximum fps	57	67
3D Mark Firestrike Extreme	5,654	6,558

Tests carried out on max settings/shader model 4.1/1440p.

TEST BENCH SPECIFICATIONS

CPU	Intel i5-4670K / Intel i7-4790K
Motherboard	ASRock Z97 Extreme4
Memory	Corsair Dominator Platinum (2x 4GB) 2,133MHz
Graphics	Nvidia Geforce GTX 980
SSD	OCZ Arc 100 (240GB)
Power supply	Bitfenix Fury 750W

MOBOS AND PSUs

Once you've got your cooling sorted, you also want to make sure you've got the best possible components that you can budget for in regards to stability. That means two items in particular – the power supply unit (PSU) and the motherboard. They are both imperatively important when it comes to overclocking. Perhaps most obvious is buying a motherboard that supports overclocking. For Intel, that's any motherboard with the Z97 chipset. For AMD users, it's currently any FM2 or AM3+ board.

Concerning power supplies, you want to be looking at a PSU that has at least 20 per cent spare capacity, in terms of wattage, over what your system requires. Preferably, push as much money as you can into it. The higher-end power supplies not only feature better surge protection, but also provide a more consistent flow of electricity between the wall and your PC parts. This should result in longer life and more stability, both when overclocking and through everyday usage.

And result! We squeezed an extra 10fps out of our GTX 980.

5 UP THE CLOCKSPEED

Start by increasing the clockspeed. Research what's most suitable for your card. In our case, a healthy overclock for the core clock should be an extra 225–275MHz offset, so we go for 240MHz.

6 NOW, THE MEMORY CLOCKSPEED

Lastly, we're going to increase the memory clockspeed. After research, we can see the community, on average, is aiming for around 450MHz. We'll try that and see how it goes, leaving Nvidia's GPU Boost to calculate exactly how much voltage we need. All that's left to do is press 'Apply' and go back into the benchmark to see how the card performs.

In the *Total War: Rome II* benchmark, we achieved a minimum frame rate of 17 at overclock, a maximum of 67, and more importantly an average of 53.6, an increase of almost 9fps towards that average. Granted, the delta between the minimum and the average is considerably greater than the stockclocked version, but who can argue with free performance?

CONCLUSION

Welcome to the world of overclocking, a place where dreams are realised, and where having just enough of those overclocking chops may mean the difference between a world record-breaking benchmark or a session crying into a pile of burnt-out chips and GPUs.

As mentioned at the beginning of this guide, OCing isn't for the faint-hearted. You can do a considerable amount of damage to your CPU and other component parts, so it's not something to be taken lightly. What's more, in some cases, the performance gains are negligible. But, if you're interested in eeking every last ounce of power from your machine, this is definitely the hobby for you.

It's something the vast majority of PC users will shy away from, and it's understandable why – the thought of placing extra strain on any of your components for the sake of a few more points in Cinebench hardly seems worth it at times. But when you're sitting there, in front of a stable 5GHz overclock on an ITX motherboard, with a chip being cooled by a single 120mm rad outperforming cores half its age, there's almost an odd sense of pride about it all. A bond between man and chip. Yes, we went there.

Benchmark your CPU

YOU'LL NEED THIS

BECNHMARKING SOFTWARE
We're using NovaBench, but there are other tools out there.

SYSTEM MONITORING SOFTWARE
CPU-Z is a good tool to use to keep a check on your hardware.

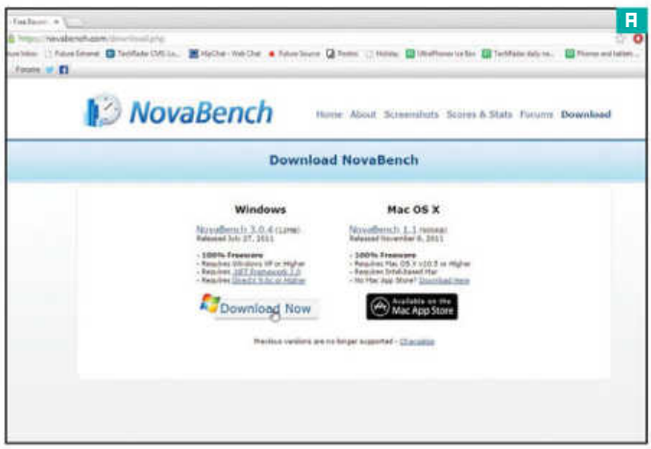
BENCHMARKING YOUR PROCESSOR, RAM and motherboard is a valuable endeavour for a number of reasons. The most obvious one is that it gives you an excellent overview of how well your PC is performing. It's convenient too, as rather than having to run lots of different tests, or use your PC in certain ways to get gauge how it performs, most benchmark tests run a range of intensive tests that push your hardware as far as it goes, as well as replicating real world use. It means you can leavethe benchmarks to run unattended while you go and do something more productive (or, let's face it, just listlessly browse the internet). Benchmarks from reputable companies do push your hardware to the limits, but they'll always be safe, so you won't have to worry about damaging your kit.

Once the benchmarks have finished you're usually given a report that outlines how your hardware performed. These reports usually lay out the information in an easy to understand way (and even sometimes come with fancy charts), meaning you can avoid having to pore over pages of confusing stats.

1 BENCHMARK FOR TROUBLESHOOTING

This leads us to another reason why you'd want to benchmark your CPU, RAM or Motherboard; troubleshooting. If your PC isn't behaving the way it's supposed to, benchmarking your hardware is an excellent way to pinpoint what the problem might be. The test results could point to a bit of hardware that is struggling which could be holding your PC back. If the benchmark fails, or causes your PC to crash, during a particular test, this is also a great way of finding out what's wrong with your machine. If you've recently built your PC it's a good idea to run intensive benchmarks for a couple of hours (if not more) to make sure your build is stable.

Benchmarking your CPU brings a number of benefits, and most benchmarking tools are free!



2 GET STARTED

The first thing you'll need to do is to download the benchmark program you want to use. There are plenty of tools available on the internet and many concentrate on benchmarking specific hardware. Because we want a benchmark that covers both CPU and RAM (amongst other things), we're going to go for NovaBench. You can download it from https://novabench.com (Image A).

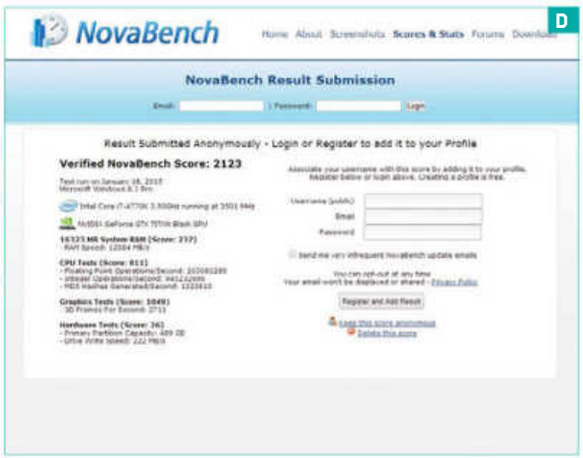
» Once downloaded all you need to do is launch NovaBench and click on 'Start Benchmark Tests' (Image B) to begin running all of the tests in the NovaBench suite. If you don't want to run all of the tests, but would rather just run specific tests on a select set of hardware, click the 'Tests' option on the menu bar.

A drop down menu will appear giving you various options to run specific tests. This is handy if you don't have time to run the full range of tests, or if you want to avoid benchmarking specific hardware for the time being.

To get the best results when benchmarking it is good practise to close any applications that are currently running. Thankfully NovaBench will remind you to close any open programs before the benchmark tests begin. A helpful window appears listing all programs that are currently open. Once they are closed, click 'Proceed' to continue with the tests.

As the benchmark tests run, leave your computer alone. A number of windows will pop up as the tests complete. Once completed a new window will pop up displaying your results.

Running NovaBench gives you an overall score which for the moment won't mean a lot, though the higher the score, the better your hardware is at performing. Underneath the main score you get a quick overview of your PC including the operating system, processor and graphics card.



3 UNDERSTANDING YOUR RESULTS

The results of the NovaBench benchmarks are broken down into RAM, CPU Tests, Graphics and Hardware tests. Each section gets its own score along with more detailed results. For example the RAM section will give you the results of the speeds of your RAM (Image C). There is an option to save your results which is helpful if you're planning on upgrading any parts of your PC. You should run the benchmark again after your changes and compare the results with the saved report from before your upgrades, letting you see how much of an improvement you've made.

Perhaps the most useful part of the results page is the ability to compare your results online. Click 'Compare These Results Online' . You'll be taken to a page where you can sign up to NovaBench and create a profile with your results (Image D). If you'd rather not sign up, or want your scores to be anonymous, simply click the 'Keep this score anonymous' at the bottom of the page.

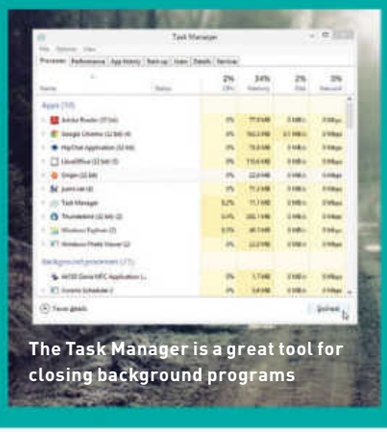
The next page will show you your results alongside a chart that compares your results with the three month average. If you're proud of your score and want to crow about it, there are a number of links to let your easily share your score on social media. Click 'Find similar score' to see results that are similar to yours and the hardware that scored those results. If your score is around the same as less powerful machines, there may be a problem with your machine. You can also check out higher scores to see what hardware you may want to upgrade to later on (Image E).

IMPROVE YOUR SCORE

Not satisfied with the benchmark results? then there are a few things you can do to improve your score without resorting to buying or overclocking your hardware. To begin with you should ensure that your PC is in as good a condition as possible before running the benchmark tests. This means scanning your PC for any viruses or malware that could impact the performance.

Once you're sure that your PC is clean make sure that all critical updates for your operating system are installed and up to date. Once done make sure all the drivers for your hardware are installed and up to date as well. Once done restart your computer and wait two minutes for all the start up programs and services to launch.

Next you should make sure that all unnecessary programs are closed down. Don't simply close any open windows; you'll need to go deeper to get the best results. First of all make sure that all the programs in the notification area of the taskbar (just to the left of the date and time) are closed down. Finally open up the task manager by pressing Ctrl + Shift + Esc and close down any Apps or background processes by clicking on them and selecting 'End task'. Now wait a while for everything to close and then re-run the benchmarks.


The Task Manager is a great tool for closing background programs

Benchmark your GPU

YOU'LL NEED THIS

THE LATEST DRIVERS
Up to date software means your graphics card behaves at its best.

BENCHMARKING SOFTWARE
In this case, the Heaven benchmark.

THERE'S A CERTAIN PANIC MANY PC GAMERS WILL BE WELL ACQUAINTED WITH. A brand new game is coming out with stunning graphics and you can't wait to play it. But then the fear sets in; will your PC be capable of running it?

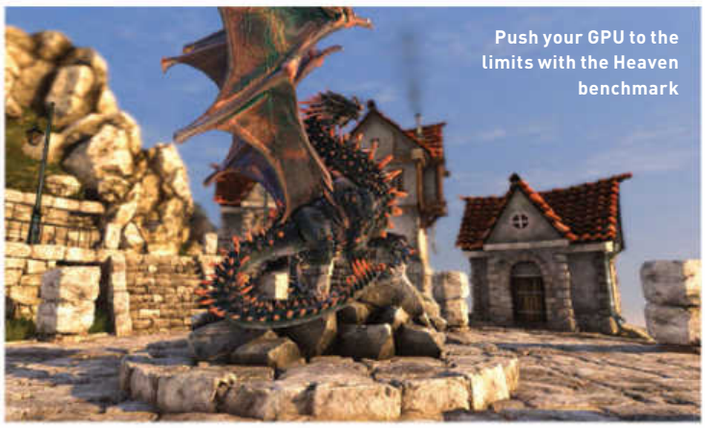
This is where benchmarking your GPU comes in. It's a great way to quickly and easily see how well your graphics card will cope with a variety of graphical demands and effects. A good graphics card benchmark will put your GPU through its paces, and the results will paint a good picture of what your GPU can and can't do well.

With these results you can then look at tweaking the game settings so that you might sacrifice some graphical bells and whistles, but you'll get a smooth and playable frame rate as a result.

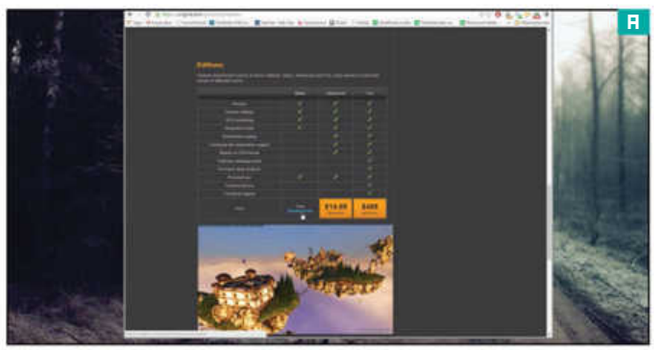
If you've just bought a beast of a graphics card then benchmarking it (and the high scores it produces) can give you bragging rights over your friends, and that's always nice.

1 WHY BENCHMARK?

Because GPU benchmarks throw a number of intensive graphical tests at your GPU, it's a great way to see how your graphics card performs under load. If you've built your own rig, or overclocked your graphics card to eke out more performance, than running a benchmark for a few hours can give you confidence that your GPU is stable. The last thing you want in the middle of a game is for your graphics card to fail, so running benchmarks can catch any problems early on. If it can run them for hours on end without problem you're good to go. If there are crashes, artefacts or other graphical glitches then you can begin working out what the problem is. One of the most likely culprits will be a GPU getting too hot, so if your graphics card fails to run a benchmark, it might be worth making sure it's getting plenty of cool air.



Push your GPU to the limits with the Heaven benchmark



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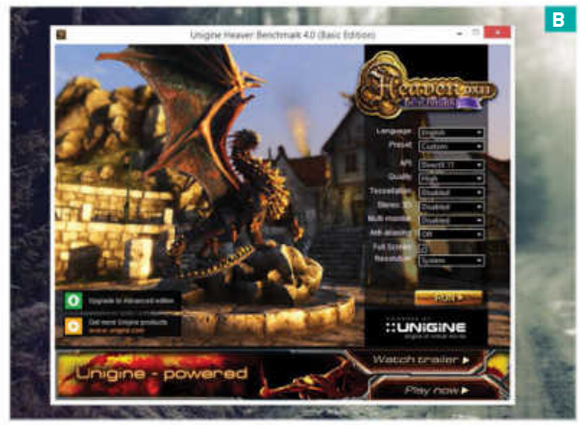


B

2 HOW TO BENCHMARK

When it comes to choosing software to benchmark your graphics card you're spoiled for choice. There are a number of popular benchmarking suites available that can put your graphics card through its paces. Not all of them are free, however, such as the popular 3DMark benchmark. There is a free version (www.3dmark.com) but the options are limited.

» For a free version which still comes with enough settings to properly test out your graphics card we'd recommend going for Heaven Benchmark, which can be downloaded from https://unigine.com/products/heaven (Image A). Scroll down the page until you see 'Download now'. Click the link, and then select where you want to download it from.

» Once installed, run the program. A window will appear (Image B) letting you select various options, such as the texture quality and the resolution you want the benchmark to run at. When choosing the resolution it's best to run the benchmark at the resolution you usually run games. That's the resolution you run Windows in as well (such as 1920 x 1080), then select 'System'. If you fancy testing out how well your gaming rig will cope with stereo 3D such as Nvidia 3D vision, you can enable 3D as well. If the benchmark runs well without any crashes or major framerate drops then you're good to grab a pair of 3D glasses and get gaming.

» If you're not sure about what settings to use, there are a couple of ready made presets that will help you get benchmarking quickly and easily. Next to where it says 'Presets' click the drop down box and choose either 'Basic' or 'Extreme'. As you can guess, Extreme will really push your graphics cards to the limit. Will your GPU be up to the task? When ready press 'Run' to begin the benchmark.


C


D

3 BENCHMARK RESULTS

When the Heaven benchmark runs you'll see a number of attractive 3D environments with the camera panning over them. This is a handy way to see how well your GPU handles this level of graphics. Just with your eyes you should be able to make out any dropped frames, graphical glitches or tearing.

» If the benchmark doesn't run smoothly then you already know that your graphics card is going to struggle with certain graphics. On the top right-hand corner of the screen you'll see and FPS (frames per second) counter which gives you a lot more information (Image C). For a smooth gameplay experience you'll want that counter to sit around at least 30. Any drops below can result in your games feeling slow and choppy. The higher this score the better, and ideally you'd like to see it at 60FPS. If your graphics card is struggling here, try changing the settings in the Heaven Benchmark settings page.

» This area will also tell you about your GPU including the model and memory. It will also record the temperature of your GPU – pay close attention to this as high temperatures can mean your GPU is struggling. An overheating GPU can also lead to problems and system instability.

» To begin recording the results of the benchmark, click 'Benchmark' on the top-left hand side of the screen or press F9 on the keyboard. Heaven will now run a number of tests and then display your results in a new window (Image D). These results with give you your average, min and max frames per seconds along with a score. The higher the score, the better. There's no quick way to compare scores with other people, but there are plenty of websites such as www.techpowerup.com and www.overclock.net that feature message boards dedicated to discussing Heaven benchmark results (Image E).

E

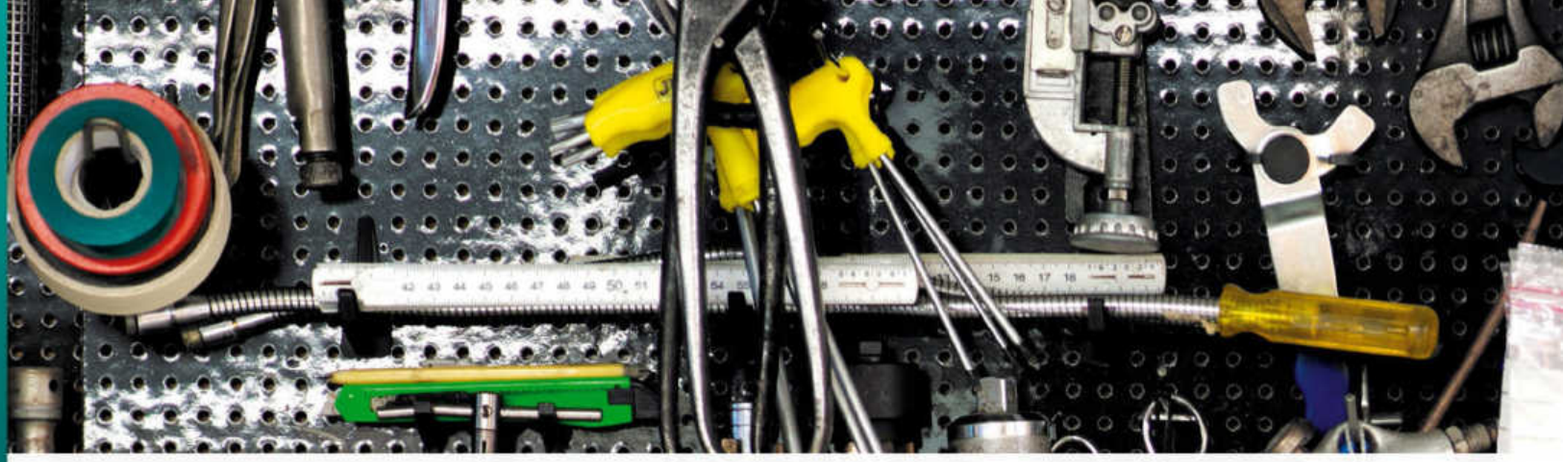
WHAT MIGHT IMPROVE IT?

If you're graphics card isn't getting the score you hoped for, there are a number of things you can do to improve the score before you resort to ripping out your GPU and replacing it with a newer model.

First of all you should make sure have the latest stable drivers installed for your graphics card. You can check this by either going to the website of your graphics card manufacturer, or using a program such as GeForce Experience (www.geforce.co.uk/geforce-experience) for Nvidia cards to check that you're running the latest drivers. If you are using experimental or beta drivers it might be worth rolling back to the last official stable release. Once done restart your computer and wait two minutes for all the start up programs and services to launch.

Close down any open programs once Windows has restarted and re-run the benchmarks. If you're still not happy, there might be another reason for the issues. Try opening up your PC and make sure that it is dust free and well ventilated, as overheating graphics cards could be the cause of poor performance and low benchmark scores. Clean the insides carefully with compressed air and a light brush. If that doesn't work, upgrade!


Nvidia Gefore Experience is a handy tool for keeping your graphics drivers up to date



HOW TO BE A TECH GURU

LUIS VILLAZON REVEALS HIS TECH SUPPORT SECRETS

Expert' is a relative term – by which I mean it's a term that our relatives use. "Ask Luis, he's the computer expert," my mother-in-law will say, to anyone who will listen. I've spent more than twenty years fixing other people's problems, so I'm used to being called an expert, but the reality is that every family has its own expert.

To qualify, you just need to be the youngest adult in the room that owns a PC. Sooner or later, your grandma or your uncle or your sister-in-law will mention that their laptop is broken or iTunes keeps crashing, and you'll feel guilted into taking a look at it. Whether or not you ultimately manage to fix it makes no difference; you'll still be the computer expert. After all, you've just spent a frustrating Sunday afternoon downloading drivers or booting in and out of Safe Mode, so you must know what you're doing.

But this is no way to live. Nobody wants to be that sort of expert; it's not effective and the hourly rate is terrible. There are people who actually enjoy pointlessly fiddling with computers, but you aren't one of those people and neither am I. What we both want is to spend the minimum time fixing computers, and the maximum time actually using them. It doesn't matter whether you are fixing your own computer, doing a favour for a relative or even fixing computers professionally; the goal is always to find the quickest, simplest fix that works.

That's the difference between an expert and a guru. A guru can listen to a long, rambling list of unrelated symptoms and decide which ones need fixing and which ones don't. A guru knows how to Google quickly for the right answer. A guru understands when to spend time on a problem and when to spend money. Most importantly, a guru doesn't spend his spare time swapping RAM or reinstalling Windows – he spends it playing PC games. A guru enjoys all of the kudos of being an expert, with none of the hassle – and I am going to teach you how to be one.

"There is no 'weird old trick' that Microsoft doesn't want you to know about speeding up your PC"

Let's start with your own PCs. You need two: a desktop and a laptop. The laptop should be cheap and the desktop should be mid-range. You may be tempted to combine the two and get an expensive laptop: don't. The desktop is for games, which means you need a large monitor, a respectable graphics card and CPU, and good speakers. If you try to do this on a laptop, you will end up paying far more for the same performance – and using an external monitor, speakers and mouse on a laptop, just turns your laptop into an unwieldy desktop. You also want to be able to upgrade the graphics card once during the working life of a games PC, and this is all but impossible to do with a laptop.

Once you free your laptop from gaming duties, you can get by with a £400 model that will do all the workaday tasks, like sofa surfing, email, word processing and spreadsheets. This ring-fences the activity most likely to cause computer problems (that is, gaming) from all the other things you need a computer for, and it means that whichever one breaks, you've got another one to use for Googling solutions.

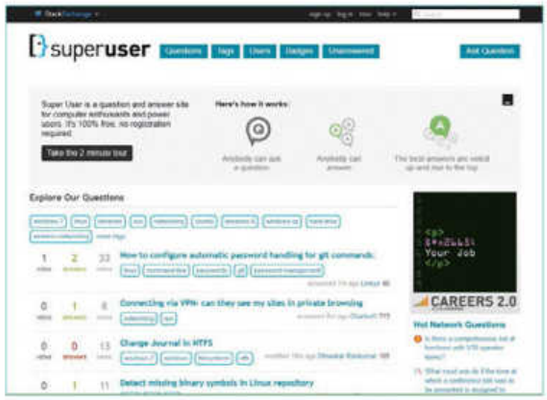
Put the desktop PC on the table, not the floor and turn the case so that it faces sideways. If you have it with the front facing towards you, like most people do, the rear becomes a stagnant tangle of cables that never gets dusted. Some of that dust will get pulled back into the case and coat your motherboard, which means the poor clearance interferes with case ventilation.

Back up both of your PCs once a month without fail. These should be complete clones of the entire hard disk using Acronis True Image (£40, acronis.com) onto an external USB drive that is at least as large as the internal drive in your PC. Use a different backup drive for each PC. Don't keep your documents on the internal hard disks at all. Put them in cloud storage, like Microsoft OneDrive, Dropbox or Google Drive. This entirely saves you from the responsibility of backing up those small, important, frequently changing files, which is most of what you need a backup for in the first place. Those clone drives are just there for disaster recovery.

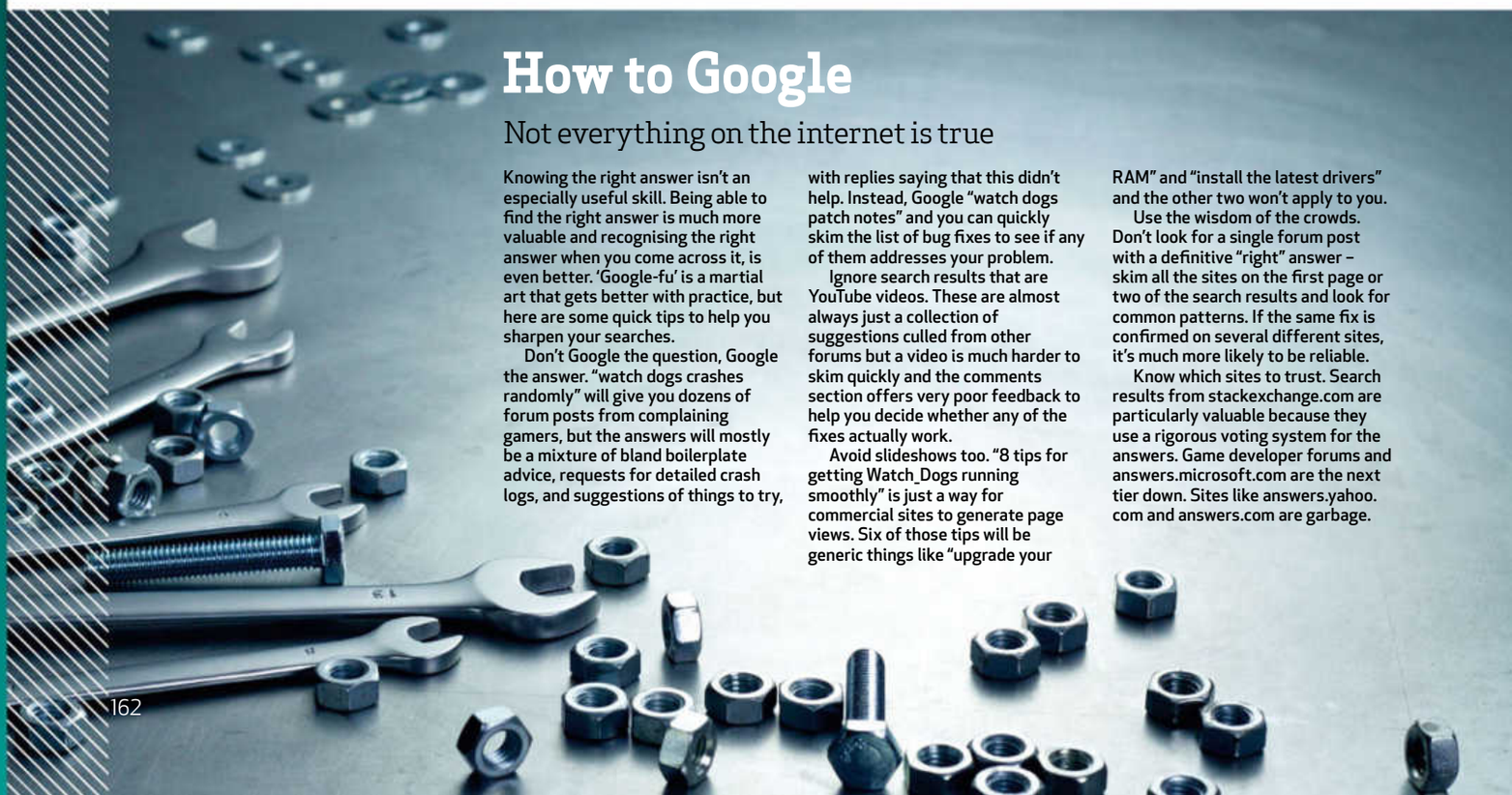
SURPRISING ADVICE

If you're giving advice to others, then you should tell them, "don't build your own computer." Ten years ago this was a good way to learn how a PC was put together, but from a support perspective you're just making things hard for yourself. It's also much harder to claim on the warranty when something doesn't work, because all the manufacturers will blame each other for any incompatibility.

Don't ever reformat and reinstall Windows. This is the last apple at the bottom of the troubleshooting barrel. It takes ages, the PC is never quite the same afterwards and it doesn't fix the problem. If you are desperate enough to reinstall Windows, you are desperate enough to get a new PC – which *will* fix the problem. Don't update your drivers, either. I know that this is the first item on



The answers at StackExchange can usually be trusted



How to Google

Not everything on the internet is true

Knowing the right answer isn't an especially useful skill. Being able to find the right answer is much more valuable and recognising the right answer when you come across it, is even better. 'Google-fu' is a martial art that gets better with practice, but here are some quick tips to help you sharpen your searches.

Don't Google the question, Google the answer. "watch dogs crashes randomly" will give you dozens of forum posts from complaining gamers, but the answers will mostly be a mixture of bland boilerplate advice, requests for detailed crash logs, and suggestions of things to try, with replies saying that this didn't help. Instead, Google "watch dogs patch notes" and you can quickly skim the list of bug fixes to see if any of them addresses your problem.

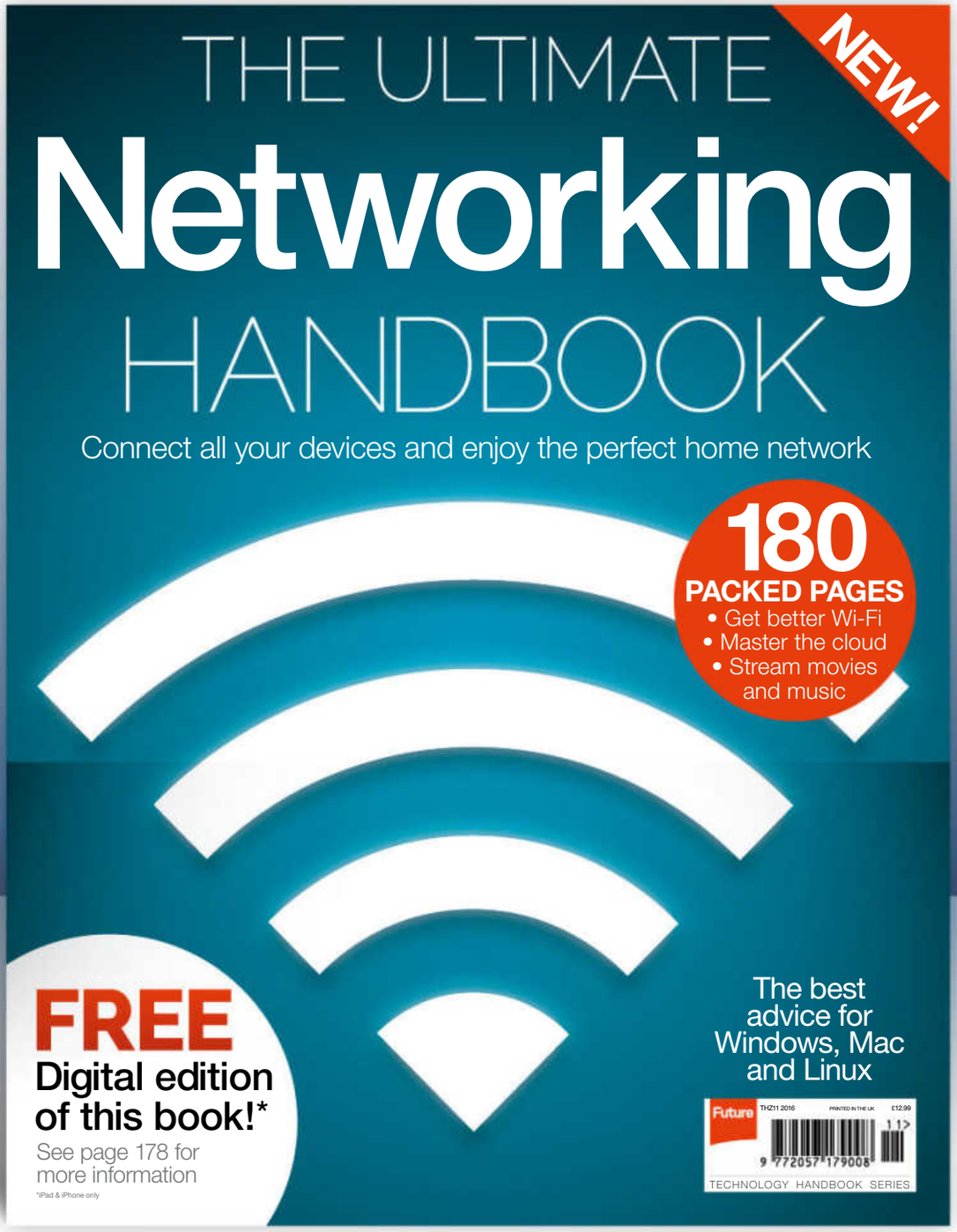
Ignore search results that are YouTube videos. These are almost always just a collection of suggestions culled from other forums but a video is much harder to skim quickly and the comments section offers very poor feedback to help you decide whether any of the fixes actually work.

Avoid slideshows too. "8 tips for getting Watch_Dogs running smoothly" is just a way for commercial sites to generate page views. Six of those tips will be generic things like "upgrade your RAM" and "install the latest drivers" and the other two won't apply to you.

Use the wisdom of the crowds. Don't look for a single forum post with a definitive "right" answer – skim all the sites on the first page or two of the search results and look for common patterns. If the same fix is confirmed on several different sites, it's much more likely to be reliable.

Know which sites to trust. Search results from stackexchange.com are particularly valuable because they use a rigorous voting system for the answers. Game developer forums and answers.microsoft.com are the next tier down. Sites like answers.yahoo.com and answers.com are garbage.

GET CONNECTED ON ALL YOUR DEVICES



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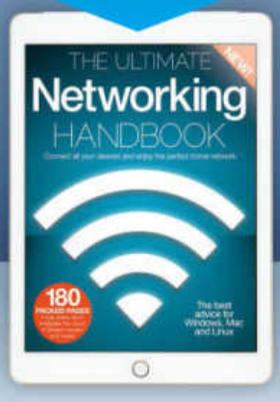

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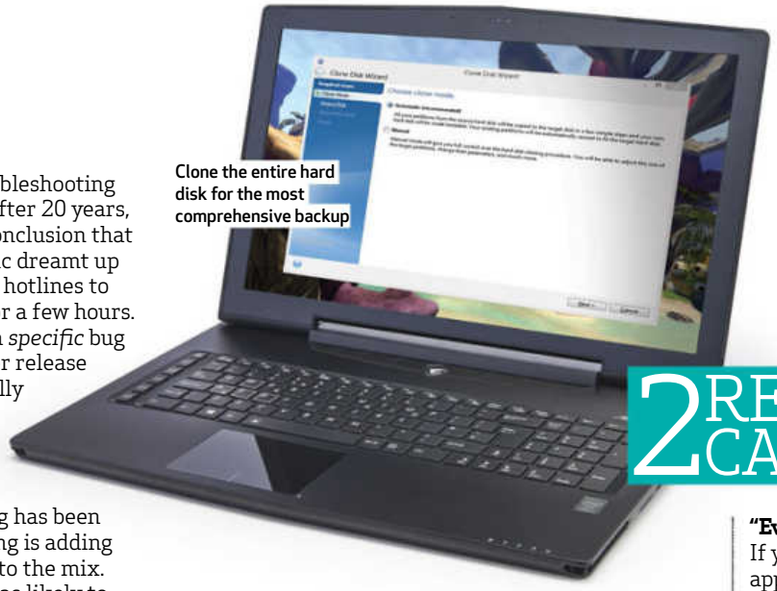


Clone the entire hard disk for the most comprehensive backup

just about every troubleshooting flowchart ever, but after 20 years, I have come to the conclusion that this is a stalling tactic dreamt up by customer support hotlines to get you to go away for a few hours. Unless you know of a *specific* bug in your current driver release that you are personally experiencing and the release notes for the new version explicitly mention that this bug has been fixed, all you are doing is adding one more variable into the mix. New drivers are just as likely to introduce new bugs as fix old ones, so higher version numbers aren't necessarily better.

With this foundation laid, your PCs will definitely never ever break or crash. When they inevitably do anyway, you will find that all computer problems fall

1 SPONTANEOUS BREAKAGE

"It was working fine until I dropped it"

The first category is for computers that abruptly transition from working to not working. This could be the entire computer refusing to boot up at all, or it could be that you can't connect to Steam, or maybe Watch_Dogs has scrambled textures. It doesn't matter *what* stopped working, the important part is that it stopped suddenly.

Spontaneous Breakage is the easiest problem to diagnose; it occurs because something changed. Either a hardware component failed or you added something that was incompatible with the rest of the machine. Identify the last time you can definitely say that the PC was working, and the problem must lie with something that changed since then. Uninstall any new software or restore your PC back to the previous full backup and see if the problem goes away. Then repeat any Windows updates and reinstall programs one by one until it returns, just to make sure.

If you haven't added anything to the PC recently and it broke anyway, then you can be sure that a hardware component has failed. If the PC won't boot, you can usually tell which component is dead by how far into the boot sequence the PC gets (see the boxout for the normal sequence of events on page 85). But if you aren't sure, you should just replace the RAM, PSU, graphics card and hard disk – in that order. This is so that you check the easiest components first, not the most likely. Your assessment of likelihood is probably wrong, and you'll save time in the long run if you get into the habit of checking the easy things first. You might think that a game with messed-up textures can only be caused by a faulty graphics card, but RAM and PSU faults can both cause this as well, and they are both much cheaper to replace.

Inevitably, you'll end up replacing some perfectly good components unnecessarily this way. So you should always buy upgrades, rather than exact replacements. That way, all your wrong guesses are at least upgrading your PC along the way – and you can hang on to the parts.

No one ever made their PC worse by adding more RAM

2 REPRODUCIBLE CALAMITY

"Every time I try, it just crashes"

If you can reliably crash an application or generate one of those error messages that end-users were clearly never meant to see, then congrats! You have found a bug.

Finding bugs is a well-paid job for some people, so if you enjoyed finding it, you should consider a career in software Quality Assurance – but bear in mind you have only found one so far, so don't get too carried away. There is generally nothing you can do about a bug except report it to the developers (if they give you an easy way to do this, of course) and hope and/or pray that it gets fixed in the next version.

In reality, this is rather like voting in a general election: it's your duty to do it, but it doesn't actually make any difference. In the meantime, you'll just have to work around the bug, but at least you don't need to waste any more time looking for a solution. After all, most of the developers won't, either. (That's satire, that is.)

Avoiding the experts

How to avoid being fobbed off and brow-beaten by the well-meaning clueless

The guy in the shop is not a computer expert; he's just someone with good interpersonal skills who knows his way around the basics. If your mum wants to set up her Gmail account in Windows Live Mail, he can help. If you come to him with your weird Blue Screen error, you'll be given some misleading flannel and then steered towards a sale.

The woman in the call centre is not a computer expert, either. She's working from a troubleshooting flowchart of simple solutions to the most common problems. Her goal is to get rid of you as quickly as possible, so she can keep her call stats up. These are not bad people, they just aren't the droids you're looking for.

The truth is that there aren't really any experts anywhere. There are just people who have come across the same problem as you, and people who haven't and are guessing loudly. To be a Tech Guru you need to start filtering out this noise. The only reason for visiting a computer shop is to see if you like the keyboard action on a specific laptop. The only reason for ringing a customer support line is for billing enquiries and refunds, or for problems with your broadband connection. Everything else you will fix for yourself, armed only with the internet.

Online is actually the only place you are likely to come across honest answers. In the real world the people who know them are tucked away doing well-paid jobs far away from grubby customers. But online you can get their help for free. Don't waste time soliciting it directly though; just skim the forums for similar questions and triangulate the suggestions from the most well-informed replies. If your problem is common enough, someone else will already have asked. If it isn't, then you won't find the answer by posting.

3 CREEPING BADNESS

Don't try and level your PC up, like a character in an MMO

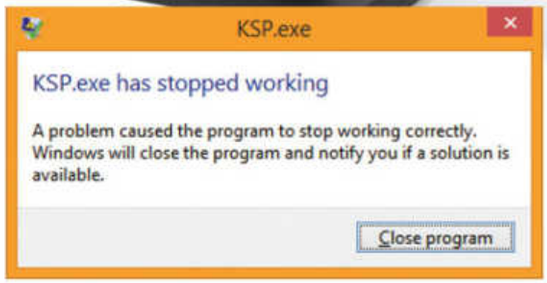
"It's just getting worse and worse"

'Badness' nearly always means that your PC is getting slower. And normally, the solution is just to put up with it. I *know* that's not what the internet tells you. But like promises of youthful skin and powerful erections, the solutions offered on the internet to speed up your PC are all scams for the feeble-minded. There is no 'weird old trick' that Microsoft doesn't want you to know about for speeding your PC up. Microsoft is extremely invested in making your PC run as well as possible, and if removing old entries from the Registry made a significant difference, Windows would already do it for you automatically.

You can make your PC run a little faster by upgrading your RAM to the maximum it supports, removing programs from the start-up group (especially your antivirus software) and uninstalling programs you don't need. But most of the slowdown comes from the inexorable bloating from Windows updates building up over time. If you want a noticeably faster PC, buy or build a new one.

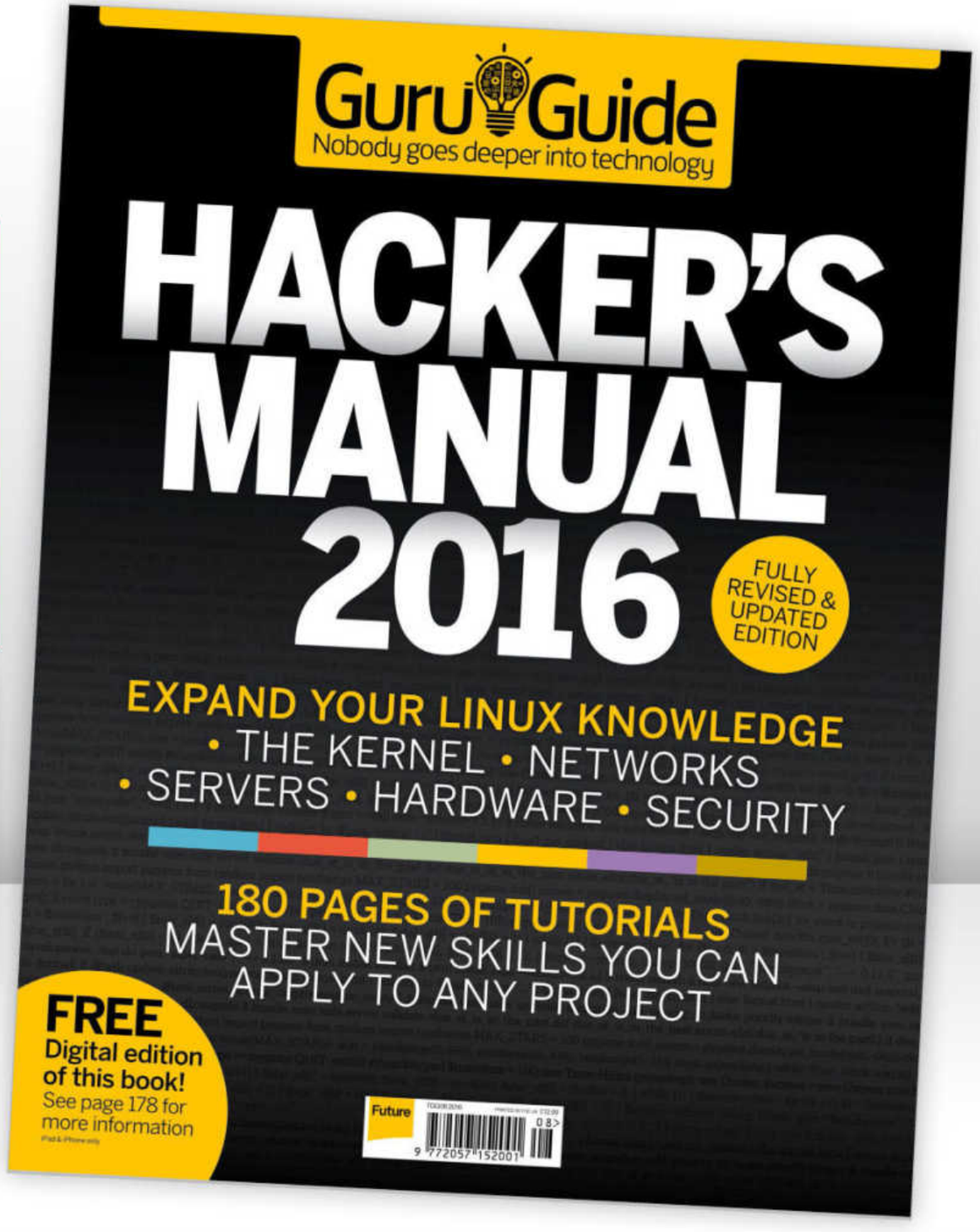
The other thing people complain has got worse over time is the heat output – especially from a laptop. Older laptops run hotter because they are trying to run newer games on older hardware, so the CPU and graphics card are running at full power more of the time. They also have collected some dust on the motherboard and on the fan blades, which interferes with cooling. You can't do anything about the former, except upgrade, and I'd argue that you shouldn't do anything about the latter either. I have never dismantled a laptop and felt that things were in better shape afterwards.

If your laptop is running hotter than it used to, try not to use it on the bed, where the duvet is going to block the vents, and hope that the graphics card doesn't blow before it comes time to upgrade. Remember, heat by itself isn't really a problem.



Abrupt game crashes are usually bugs in the game or its mods

POWER UP YOUR LINUX SKILLS!



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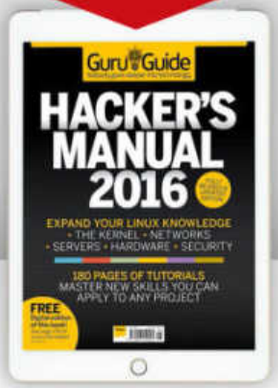

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4 RANDOM WEIRDNESS

If your laptop runs hot while gaming, that's quite normal

"Sometimes it just freaks out for no reason at all"

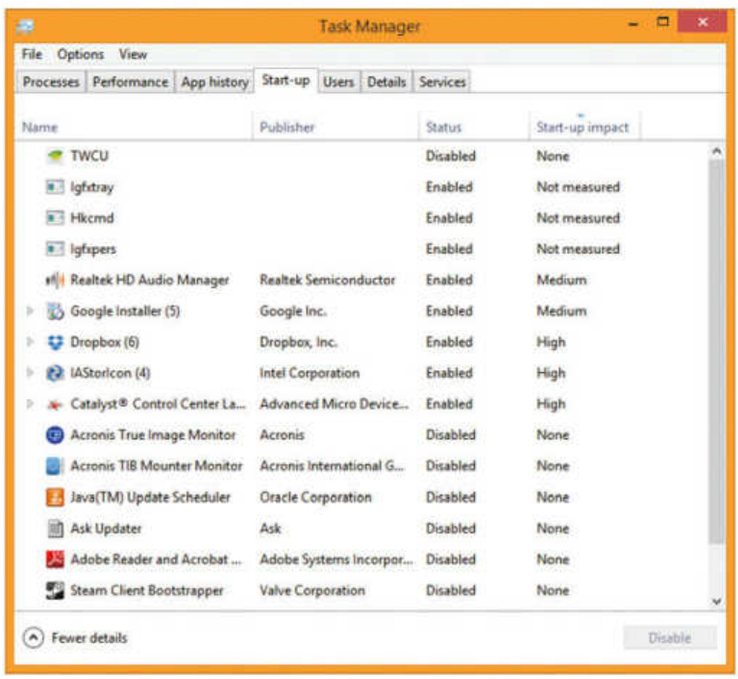
There are three kinds of random fault: loose connections, overheating and memory errors. You can tell the difference quite easily. If it freaks when you pick it up, it's a loose connection: some component or wire internally isn't quite making the connection it's supposed to be, or at least isn't doing it reliably.

If it freaks when you have been watching movies or playing games for a while, perhaps accompanied by overly enthusiastic fan noise, it's overheating. Everything else is a memory glitch. You can fix memory glitches by replacing your RAM and the other two kinds usually can't be fixed, so you should just replace the RAM anyway, in case you were wrong about which kind you have.

Random weirdness that happens only extremely occasionally isn't worth doing anything about. For instance, if my PC reboots itself spontaneously once a week, I would rather take a few calming breaths and get on with my life than waste several days hunting down a fault that is extremely hard, if indeed possible, to reliably reproduce.

On the other hand, if it reboots five times a day then this is frequent enough not to count as random at all, and more to the point it's damned annoying. You can treat this sort of fault as Spontaneous Breakage and take appropriate measures by referring to that section.

5 OMINOUS PORTENTS



Removing start-up junk is one of the few go-faster tips that works

"I'm sure I'm infected"

When people come to me for computer advice, I have learned to listen to the symptoms, not the diagnosis. Some people are convinced that their PC is constantly under attack and see every unexplained behaviour or error message as evidence of a virus infection or a hacker. If you are one of those people then stop it! Provided that Windows is updating automatically and you have changed the admin password on your broadband router from the factory default, avoiding viruses and hacking is mostly a question of not being an idiot when you click links.

If your browser home page has changed by itself, or you can't open google.com, then you've probably got a browser hijack. This is malware, but it isn't a virus and it isn't Ebola. Download the Microsoft Malicious Software Removal Tool and be done with it.

Do you really need to upgrade it? *Really?* Think now

BONUS CATEGORY

RAINBOW CHASING

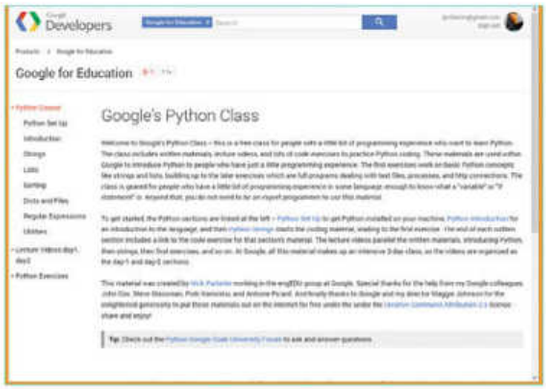
"I just want to try out the latest cool thing"

A PC is like a character in an MMO. When you start at level 1, you fight wolves and gradually you upgrade your equipment and can take on several wolves at once. But no matter how powerful you become, there will always be new gear you could get, and Chromium Ultra-wolf Den Mothers that you could be fighting. Rainbow-chasing is when you make life hard for yourself by trying to fix problems that don't exist. Overclocking your PC, just to get a bigger number in your benchmarking tool, say; or configuring a RAID0 array of disks, when hard disk performance isn't even a bottleneck for you. A lot of "What's the best way to upgrade?" type of questions are examples of Rainbow Chasing.

Upgrading is generally a good thing but there are two pitfalls you need to watch for. Don't upgrade your PC for the sake of it. You should upgrade so that you can run new software that exists now, not so that you'll be ready for any new software that might come along in the future. You can't tell how long it will be before something comes along that you need new hardware for – and by the time it does, your upgrade might not be graded far enough up. Secondly, you need to know when to upgrade the components and when to upgrade the PC.

Here's what I do. With every other version of Windows, I will buy a new desktop or laptop with that version preinstalled. On the odd-numbered releases of Windows, I'll just upgrade the existing machine. When I buy a PC, I'll specify one notch above the current mid-range for CPU and graphics card, and get the maximum RAM that Windows currently supports. I normally get whatever the default hard disk size is at the time. After a year, if I want to run an application that needs more RAM or a faster graphics card, I'll upgrade. If it needs a faster CPU, I'll get a whole new PC. I have never run out of disk space on any PC ever.

A very common question for a Tech Guru is "Which new graphics card/laptop/motherboard do you recommend?" And the correct answer is to look at PC Format magazine. The team regularly covers graphics cards, motherboards, CPUs and looks at full systems and laptops once a year. This leaves the question of how much you should pay for such things. The right price for a



Learning Python is straightforward, useful and free

Learn to program

It's like Pilates for your brain

Programming is an extremely helpful skill for a Tech Guru. Lots of command line operations become easier if you know a little programming, particularly in Linux – but much more importantly, it teaches you what a computer really is.

Programmers are like Neo: they don't see files and icons, they see resource handles. Memory isn't just a quantity, like the fuel in your tank; it's a collection of discrete integers and floats and strings. When you understand how the house is built, you'll know which walls you can safely remove and which will bring the ceiling down on your head.

Programming means debugging, and the mindset you need to track down a tricky bug is exactly the same as the one you need to diagnose every other computer problem. Programming is like classical music theory for computer troubleshooting. You can teach yourself to strum some chords without it, but you won't become a great musician that way.

As soon as you can write a simple program, more complicated programs lose their mystique. And if you can write even a modestly useful app or a mod for a game, then your computer itself will be demystified to a degree that is impossible to overstate. Programming is such an incredibly useful skill that it should be compulsory for all five-year-olds, never mind aspiring Tech Gurus.

Happily, programming is easier to learn now than ever. Python is a good language to learn first – it's a widely used, serious language, but it is designed to be quite readable and simple.

You can learn the basics for free in a few weekends at developers.google.com/edu/python and learnpythonthehardway.org. Don't be put off by the 'hard way' part; if you can complete a sudoku puzzle or Professor Layton and the Curious Village, you can learn Python too.

What should happen

Understand a normal boot sequence to recognise anomalies

When your PC is switched off but still plugged into the mains (or laptop battery), the motherboard still receives power on the 5-volt standby rail. This provides power to the circuitry that monitors the power button.

Pressing this button signals the motherboard to tell the power supply (PSU) to fire up properly and also pulls the voltage to 0V on the reset pin for the CPU. This puts the CPU into a known start state, with default values loaded into all the registers, and sets the instruction pointer to the start address of the BIOS.

Between 0.1 and 0.5 seconds later, the voltages from the PSU have stabilised and it signals this by putting +5V on the Power Good line (pin 8 of the ATX connector). The tells the motherboard to release the reset line, which allows it to return to +5V.

The CPU now begins executing the Power On Self Test (POST) in the BIOS or UEFI code. This initialises the RAM and the PCI bus. If there is a problem at this stage you'll receive a series of beeps to indicate the problem; a single beep indicates a pass, and control then passes to the video card, which executes its own video BIOS initialisation routine. Once the video subsystem is working, control comes back to the BIOS or UEFI and you'll either see the summary screen, or just a pretty splash screen.

While this is displayed, each drive is checked in turn until it finds a bootable one. Control passes to the boot loader program stored on this disk, which copies the Windows kernel and basic drivers into RAM. After that the Windows logo appears, the boot loader copies the registry into RAM and loads the remaining drivers. Once that is complete, the boot loader hands off to the Windows kernel and the login screen appears.

graphics card is £200. For a laptop, it's £400 for a basic machine and £1,000 for a fancy one. For a motherboard it's £100, although the only reason to upgrade the motherboard is when upgrade the processor as well and if you are doing that, you may as well look at a whole new machine - you'll get a much better PC, with less hassle.

HELPING OTHERS

As a Tech Guru, you have to do more than diagnose the problem. You must also consider who is asking for your help and choose the best solution. By that, I mean the best solution for *you*.

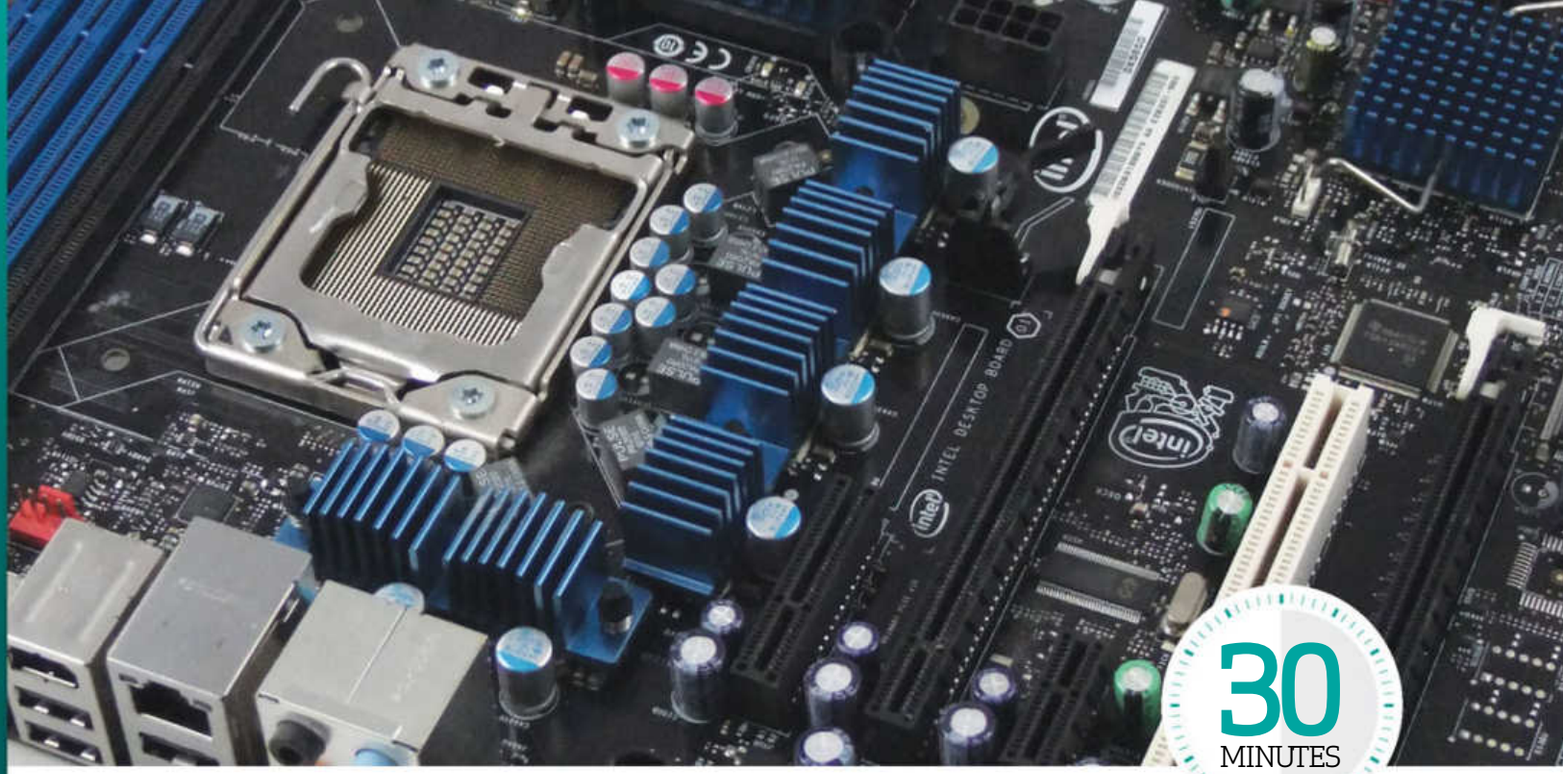
For family members, you need the quickest resolution, because they will come back to haunt you if you don't fix it on the first try. Swapping RAM modules around is a quick and safe thing to try, but reformatting and reinstalling Windows will be like cutting the head off a hydra: you may fix the original problem but three more will grow in its place, as you try to restore all the drivers for their 15-year-old printers and off-brand sound cards.

With friends and neighbours you are much less invested, so wherever possible you should recommend new kit. My experience is that this is generally what they are hoping you will do anyway; your pronouncement will be used as bargaining leverage with their spouses or parents, to justify a big spend. If you try and save them money, they will resent you for it and the next time their PC breaks, you'll be blamed for not euthanising it last time.

If you can boot this far, the motherboard is probably fine

If you are fixing computers for customers, your overriding priority is to safeguard their data. Before you so much as open Device Manager, you should clone their entire hard disk onto a removable drive of your own. This will feel like a ridiculous precaution every single time, until you actually need it, whereupon it will feel like the best advice anyone has ever given you. Remember: if data is lost *for any reason* while you are sat in front of the keyboard, you will be blamed. Cloned hard disks are like save points: you can afford to be more adventurous, if you know you can hit F9 and reload.

Is that all? Are you really a Tech Guru now? Of course you are! Gurus don't have all the answers, they just know how to remain calm under fire while they look for one. They know where to look and they know the answer when they see it. You can do all these things, and all that you need now is the self-confidence to carry it off. If anyone tries to call you an expert, by all means deny it. But if they call you a guru, just smile knowingly and humbly.



30 MINUTES

Diagnose boot issues

You've put it together, and it doesn't work. What now?

PROJECT GOAL

A stable PC
Fix a system that won't pass its POST, or at least find out why.

REQUIRES

Mobo manual
You'll need this to establish that your motherboard, RAM and chip are compatible, and see where everything plugs in.

Pozidriv screwdriver
For any disassembly necessary.

Thinking cap
Some problems might need a little brainwork to resolve.

Damn, it's dead. You've just pressed the power button and there's little sign of life, let alone an operating system. You may see text from the BIOS, a blue screen or nothing at all. There may be silence, or a flurry of beeping and frantic fans. Never mind driver problems; this is more fundamental than that. Your box has failed at the first fence and the POST has bombed.

The POST (power-on self-test) is the very first software your rig runs, and it lives within the BIOS. It runs basic diagnostic tests on your hardware, checking that it's present and working. Only after this is confirmed will the bootstrap loader be accessed and your operating system cranked into gear. The POST's main jobs are to check the processor registers, verify the size and integrity of your RAM, check that the graphics card is ready, check the system clock, interrupts and such, pass control to other hardware system BIOSes (notably the graphics card), and finally shake hands with your drives and select a booting one.

Should things go wobbly during the POST, you know something fundamental is going wrong. At this point your BIOS will tell you with a series of beeps, rather like Morse code, possibly accompanied by little LEDs. It'll then shut down, freeze or start booting again. No beep codes doesn't mean the end of the line, though; there are plenty of situations that the POST can't catch, or which cause it to fail before it even gets going.

Getting naked

If you suspect a short on the case, it's a good idea to get systematic by pulling everything out and starting afresh. It can also pay to run a system outside the case before you build it, especially if you're recycling parts you're unsure about.

Sit the motherboard on a firm, clean and non-conductive surface, then plug in your power supply, processor and cooler, and fire it up by shorting the power pins with something metallic. It might not get far, but you should get some beeps that refer to memory (expected and good), or your processor (bad). Alternatively, there may be silence (possibly worse).

Add your hardware until you find your problem – or not. It may be indeed have been your case. Just don't touch anything when it's powered up. Not because you'll get a shock (there's nothing nastier than 12V outside the PSU) but because you're likely to cause a short circuit yourself.


Take the case out of the equation to see if it's at fault.

Stay frosty

Time to remember Occam's Razor: "Entities must not be multiplied beyond necessity." Or, put another way, the simplest solution is most likely the correct one. It was good enough for Einstein, Planck and Heisenberg. If the problem could be either a power spike causing a power line on your PCB to short, or you forgetting to turn it on at the plug, you should probably check the plug first.

Start with the basics and try not to make assumptions. Listen to your system. Read what the POST flashes up on the screen. Are all the fans firing up? Is the BIOS beeping at you? Modern PC components are very reliable and thoroughly tested, so spontaneous failures are rare. No matter how experienced you are, it is all too easy to skip a simple, but obvious step. Remember, the most fallible component in your system is probably you.

The POST dates back to the original IBM PCs, when memory was less reliable and things failed more often. Much of it is concerned with checking memory integrity. It's not exactly an in-depth process – more a set of simple call and response signals and checksums to see what's on the end of the wires, and whether it responds properly.

There are two basic sources of POST errors. Either the tested component is a burnt wreck that will never work again, or (much more likely) you've plugged it in crooked, in the wrong place, or forgotten something simple and fixable. This is a little glib perhaps, but there really isn't much middle ground with modern kit; boards and chips generally work as advertised, or not at all. This is good news really, as these days memory errors are more likely to happen because you've got the wrong sort, or it's in the wrong slots rather than because it's a pile of dead chips.

Jargon buster

BIOS
Basic input/output system – a small machine code program stored on a chip on your motherboard. It contains just enough code to get your PC to use hardware and run an OS. It's generally unused once your OS is up and running.

CMOS
An area of non-volatile memory within the BIOS that stores basic hardware configuration. This is what you can configure when you boot into the BIOS to change things.

POST
Power-on self-test– a series of simple checks your BIOS makes to ensure things are plugged in and working properly. It runs once when you boot.

TOP TIPS
STATIC KILLS
Or so we're told. It's good practice to earth yourself on the case or other metal object before diving in. It's not quite the danger many quote, though (wearing an earth strap is a bit excessive).

First, read the manual. Yes, we know how tedious that is. If this is the first time the combination of motherboard, processor and RAM have come together, check here to see whether they are supported. Just because you can plug the chip in, it doesn't follow that the board can handle it. The manual will also detail what gets plugged in where. Yes, this is basic stuff, but remember the Razor. Have you been fiddling with BIOS settings? It's easy enough to set RAM timings that fail. If you've just made some changes, undo them. If you've just added some hardware, remove it.

Beep or no beep

At this stage, a lot depends on whether you get a POST error code (consisting of one or more beeps). These give you a pretty good idea of what's at fault (see 'Beeping beeps', below). If you get silence, then you probably have a power issue – a missing connection, blown fuse or worse. If the problem is a fan failure, then your BIOS may have stepped in to stop proceedings.

If there are no error codes, you'll have to do a bit more detective work yourself. If you're quite certain everything is plugged in firmly, start by removing things until you see a change. Remove any external hard drives and USB drives, then the internal drives. Still nothing? Try removing any expansion cards.

Next to go is the memory. Remove it all. You should now get an error code complaining that there's no memory – if not, you have motherboard or power problems. Fit one stick and try every suitable slot (the board may only respond to the slots in order, or it may not care). Try each stick on its own in turn. A faulty stick or slot will soon identify itself.

If the RAM checks out, then we are down to the bare bones. Pull the graphics card and your BIOS should produce an error code. Same story with the processor. If you still get no error codes, then all you're left with is the PSU or the motherboard.

One tricky customer is the random short circuit or broken PCB line (although nothing is actually random – ask any mathematician or physicist). Flexing a mobo can cause a crack in a PCB line, which may close and open as you fiddle with things. Alternatively, there may be a little bit of something conductive floating about the case (it doesn't have to be big). These can be awkward to fully diagnose. If you suspect a short, then full disassembly may be called for (see 'Getting naked', opposite). Ideally any suspected dead component should be tested in another system before being binned – a luxury perhaps, but it's nice to be sure.

We've built dozens and dozens of systems here in our secret lair, and we've had our fair share of DOAs. Each time there's the initial panic, fearing some expensive component (often on loan) has crashed and burned. Then we look again, and wouldn't you know it? We forgot to plug in all the power cables, or some such. So don't panic, the chances are it is recoverable. If not, it's not too hard to track down the culprit.

Beeping beeps

If your box is beeping, it's trying to tell you something important, so listen. You used to need a system speaker to hear these tones, but modern boards have their own little built-in beep-maker. A system speaker isn't your regular sound system, either – it's separate and specifically for error codes, and we haven't seen one for years.

IBM created the original set of beep codes. One long beep and two short, for example, means it can't find a working graphics card. The BIOS makers have added to the error codes over the years. Unfortunately, there is no standard for what beeps signal which problem, and although there are some consistencies, (small numbers of short beeps are mostly memory errors), there are enough variations for it to be really annoying and require specific documentation.

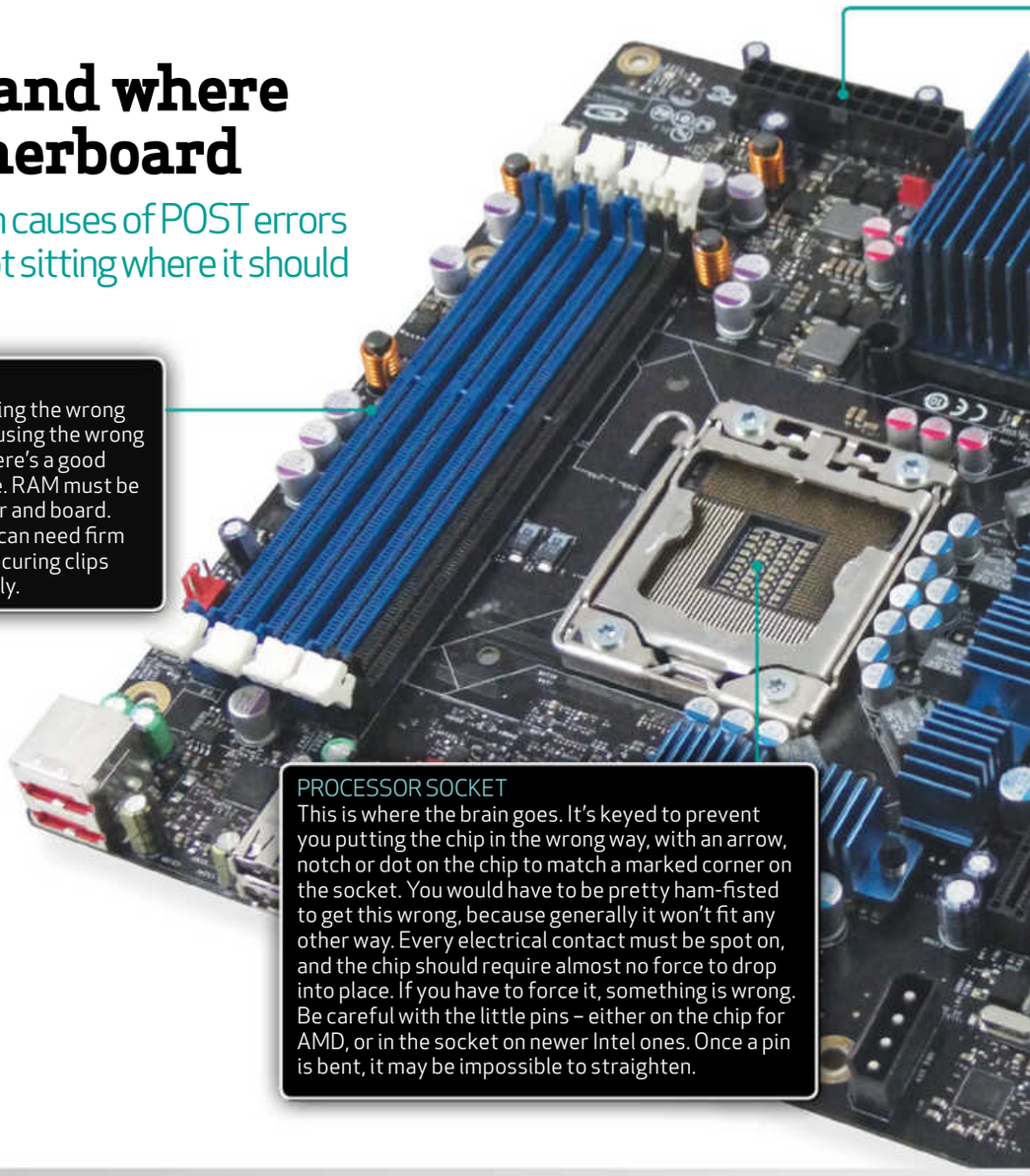
If your system beeps, you can use the manual or a device with a working internet connection to decipher them. Try searching for POST error codes – the top articles are all pretty good, especially the TechNick one. More beeps don't necessarily mean a more serious problem. Once you've located the source of the issue, remove and re-seat the offending hardware, then try again. If it's a powered component, check that the power is plugged in, and try a different power cable if you have a spare. Try swapping things around as described above if it's a memory error.

The error codes are a decent starting point, but they don't tell you the exact problem, or how severe it is. It may be a simple seating issue, or a component may be trashed.

BIOS makers have added their own error codes, but there's no standard.

What's what and where on your motherboard

One of the most common causes of POST errors is a component simply not sitting where it should



DIMM SLOTS
Some very common problems are fitting the wrong RAM, putting it in the wrong slots, or using the wrong capacity. If this is a new build, then there's a good chance your problems stem from here. RAM must be properly matched with your processor and board. Your manual will detail all this. Sticks can need firm coaxing to get into place, too. If the securing clips don't engage cleanly, it's not in properly.

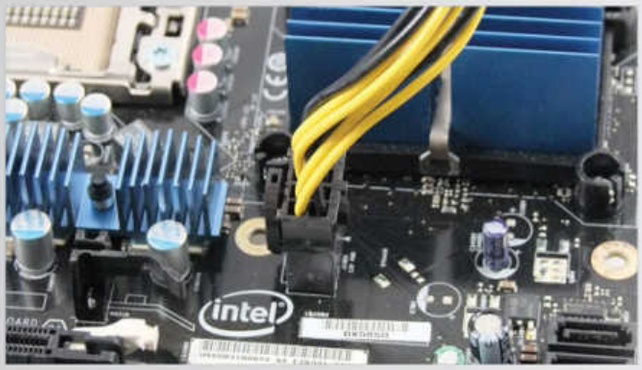
PROCESSOR SOCKET
This is where the brain goes. It's keyed to prevent you putting the chip in the wrong way, with an arrow, notch or dot on the chip to match a marked corner on the socket. You would have to be pretty ham-fisted to get this wrong, because generally it won't fit any other way. Every electrical contact must be spot on, and the chip should require almost no force to drop into place. If you have to force it, something is wrong. Be careful with the little pins – either on the chip for AMD, or in the socket on newer Intel ones. Once a pin is bent, it may be impossible to straighten.

Are we all plugged in?

Never underestimate how easy it is to make a fundamental error

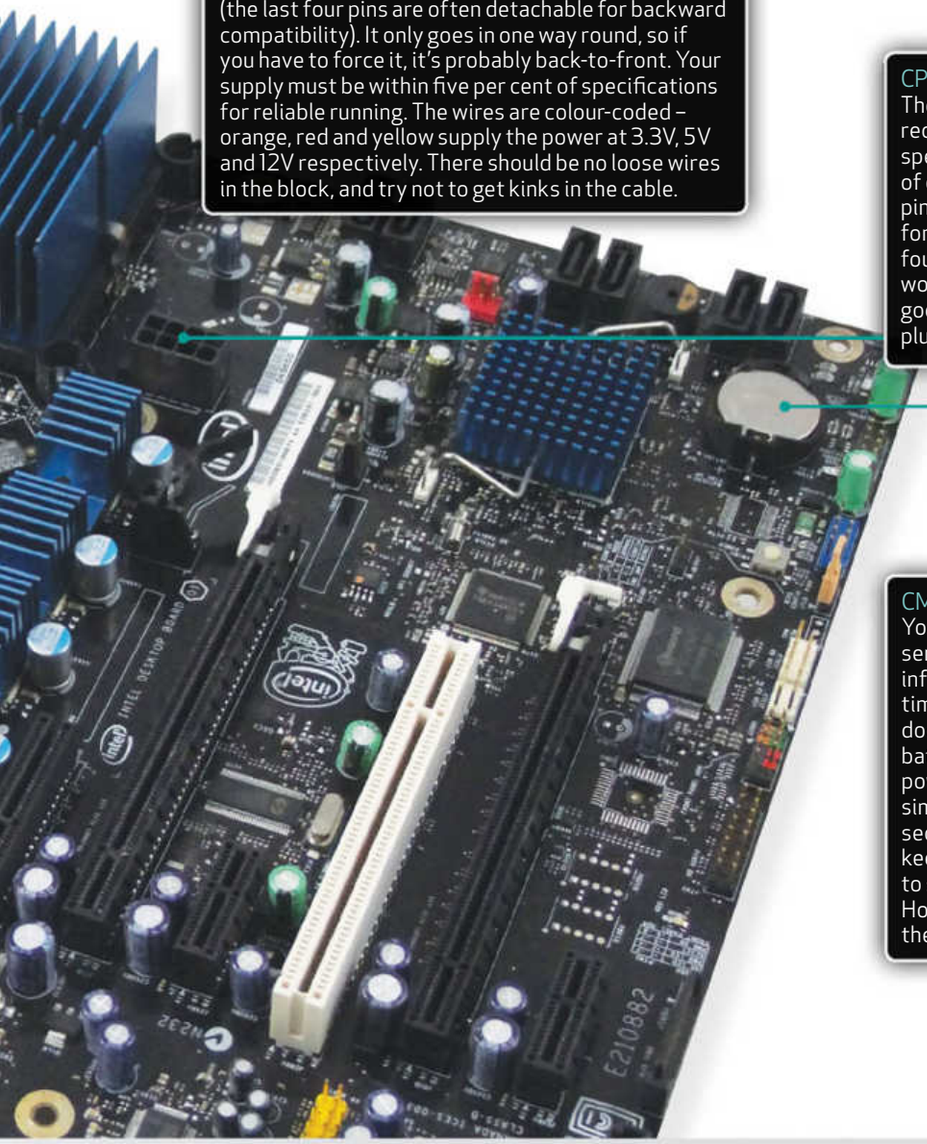
1 Is it really on?

On the back of your PSU, there is probably an innocuous-looking black power switch, which is rarely touched in everyday use. It's easy to forget about it and start worrying about dead components when all the time you haven't switched on the juice. If this fails, try replacing the kettle lead; you may have a faulty one, or a blown fuse.



2 Processor power

Chips get their own power supply, and it's easy to forget to plug this in. It'll use either an eight-pin block or a four-pin block. Often the power supply lead splits the eight-pin into two four-pins to make it compatible with both. It's the socket next to your processor, often called '12v ATX'. Another easy miss is the power for your CPU cooler.



MAIN POWER CONNECTOR

The ATX standard dates from 1995. It was originally a 20-pin block, but now usually appears as a 24-pin one (the last four pins are often detachable for backward compatibility). It only goes in one way round, so if you have to force it, it's probably back-to-front. Your supply must be within five per cent of specifications for reliable running. The wires are colour-coded – orange, red and yellow supply the power at 3.3V, 5V and 12V respectively. There should be no loose wires in the block, and try not to get kinks in the cable.

CPU POWER BLOCK

The CPU socket supplies power, but processor requirements soon outgrew it. This power block is specifically for the processor. Depending on the type of chip fitted, it'll be a block with either eight or four pins. Often the cable comes with two four-pin blocks for cross compatibility. If your chip only needs a four-pin block and the board has an eight-pin, don't worry, just plug in the full eight-pin connector. It only goes in one way around, so don't force it. Without this plugged in, your system is dead in the water.

CMOS BATTERY

Your **CMOS** (complementary metal oxide semiconductor) is the part of the BIOS that stores information such as what hardware you have, memory timings and so forth. It draws very little power, but does need some, which is why it has a little coin battery. If your system loses the date and time after powering down, this battery is on its way out. It's a simple replacement – just be careful not to bend any securing clips. These days the battery is just used to keep the clock going, because flash memory is used to store hardware settings and requires no power. However, the term CMOS is still used for the part of the BIOS holding variable data.

3 Video power

Another easily overlooked connection is the graphics card's power supply. They can be hungry things, and only mediocre cards can run off the socket power alone. There are one or two six-pin blocks and/or an eight-pin block. Just make sure they are all filled. It's best to use cables directly from the PSU rather than adaptors.

4 Front panel

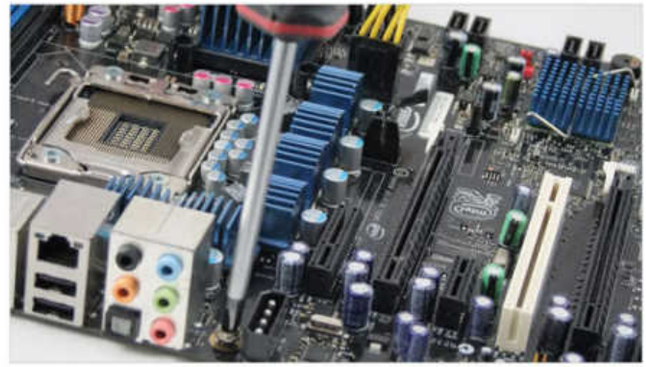
The polarity of the reset and power switches isn't important. If your activity lights fail to light, try reversing the connection. Try disconnecting the reset switch if you suspect a short. You can fire a system manually by shorting the power pins if you suspect your case switch, but make sure you've properly identified them first.

More than cables

OK, so it's all plugged in. What's next to consider?

1 Get in there

Video cards can take considerable force to get properly seated, which can be worrying, as flexing your board is really not a good idea. Make sure the mobo is fully supported with stand-off posts before applying pressure. Many boards have securing clips for the card. If you can't get these to click in neatly, the card needs pushing down further. Try removing and reseating if the angle is at all crooked.



2 Unwanted shorts

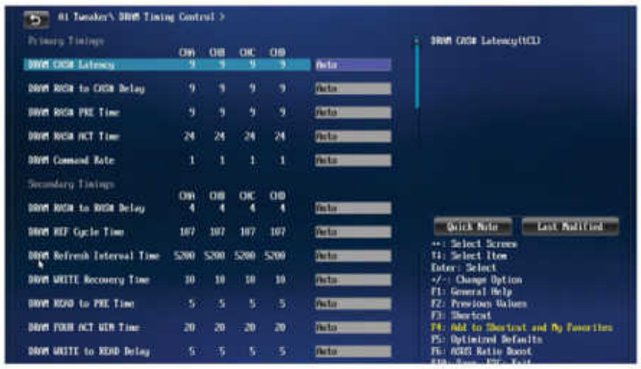
If an electrical conductor touches your board, it can cause a short circuit on the fine network of tracks, which is guaranteed to cause trouble. Check the posts that the board sits on. Did you install them all in the correct places? There is no standard pattern and it's easy to get one in the wrong place. You won't see it from the top, and a misplaced one can easily cause a short circuit on exposed soldering.

3 Loose screw

A short anywhere will call a halt to operations. Did you drop a screw in there? It's easily done. Are there any wires touching the board that may have worn insulation? It's good practice to have all wires routed well away from the board, especially underneath, where there are sharp soldered connections that can cut into wires. Many cases have a tray under the board to keep wires out of such trouble.

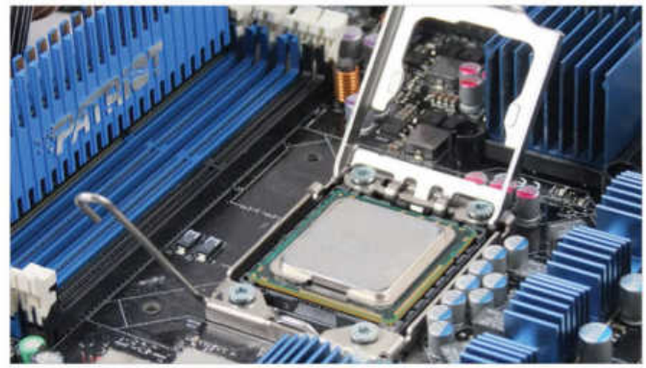
4 Memory slots

Are your memory modules all fully seated, with the securing clips in place? Are they in the right slots? Check the manual to make sure. Wrongly configured RAM is a common cause of dead boxes. It must match the board and processor. Try booting with a single stick of RAM, or one pair for coupled systems. You may have a faulty RAM socket or a faulty stick, so mix and match to pin it down.



5 Memory speed

If you can boot with at least one stick of RAM, enable the XMP profile (basically factory-approved overclocking) in the BIOS if the board supports it, or set the memory speeds in the BIOS manually to match your stick's specs. If your sticks are rated at a higher voltage than the default settings allow, it can cause stability problems.

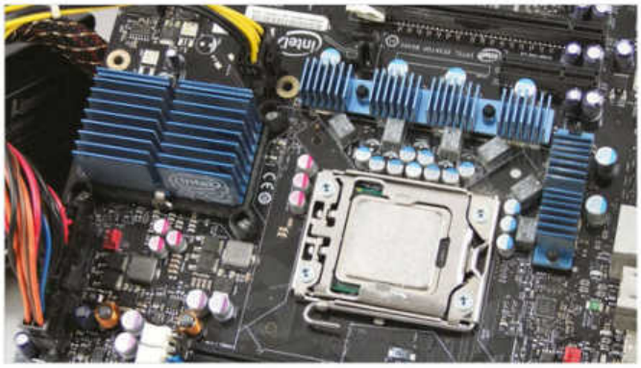


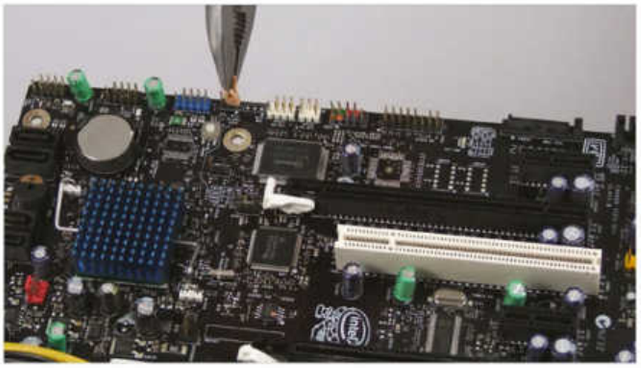
6 Processor all square?

Is your processor seated cleanly, flat and the right way round? There is a visual indicator on the chip (often an arrow) and the socket has a similar indicator, or is obviously asymmetrical. Never force the chip into place – we don't want a bent pin. They can be coaxed back to vertical very, very carefully, but if one breaks, you're stuffed.

Getting tricky

So you've covered all the basics. Now what?



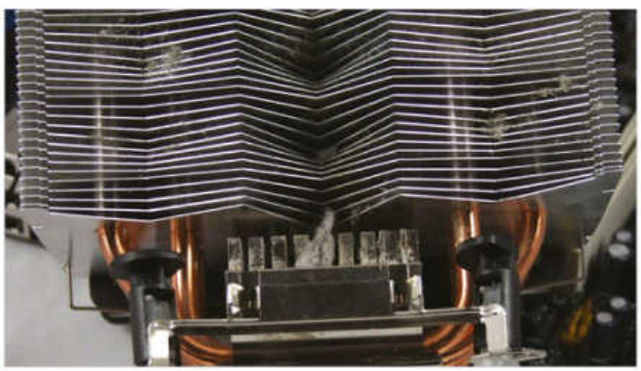


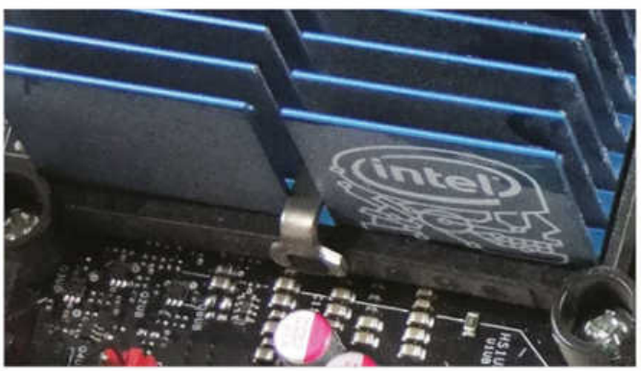
1 Re-seat your cooler

Your processor cooler needs to be seated firmly in place and completely flush, or the chip will overheat. Are all the connectors snug and is the cooler level? Did you put a (tiny) bit of thermal paste on? The contact between the top of the chip and your cooler needs to be good and true. The motherboard's thermal cut-out will trigger if it detects the temperature going too high, which may only take seconds.

2 Clear the BIOS

It will wipe some useful information, but resetting the CMOS can fix some setting woes. The simple way is to go into the BIOS and restore the factory settings, but this isn't much help if you can't get into the BIOS setup. Most boards have a jumper or DIP switch that will reset the CMOS. Once cleared, your BIOS will redetect all your hardware on booting, which may clear an overlooked incompatibility.





3 Dust the fan

Does the chip fan go mental before the whole system locks up? If your cooler is fitted properly, the problem could be restricted airflow. Often there's an accumulation of dust deep inside the cooler, sitting between the fan and lodged in the cooling fins, or hair wrapped around the fan. A fine pair of tweezers or more thorough disassembly will put things right. If your rig sits on the floor, this is a common woe.

4 Clean the board

A grubby board may have collected dielectric material, or the grot may be acting as a blanket of insulation. Blow dust away and use a soft brush on more stubborn bits. If it's really grubby, you have the death or glory option of washing it (yes, really). Remove the CMOS battery, and use clean water. It must be completely dry before running any power. If it works, glory. If not, tough, it's properly dead now.

Power failure

Power supplies are tricky to diagnose unless they start to smoke, or there are loose wires in the power blocks. PSUs are sealed and have fans, so they attract dust that insulates components and clogs fans. If your motherboard appears dead and you've checked that everything is plugged in, your PSU deserves suspicion; it may be that it just can't reach operating voltages any more.

Symptoms vary, and affect almost every other component. They are also easily confused with other failures. If it's good enough to fire the box, but not for sustained use, a PSU failure can get nasty – unreliable supply during writes can leave unreadable junk smeared across your storage drive.

This tendency to affect all components does at least give you a decent clue that power is the problem. Thankfully, they have a tendency to all fail together, but not always. A more obvious sign is a hard-working PSU fan. It may fail only under heavy load, such as right in the middle of an intense bit of 3D gaming. If you're upgrading a system, particularly the graphics card, are you sure the PSU can cope? Capacity should exceed requirements by at least 20 per cent. Trying to recycle old PSUs can also cause issues with inadequate 12V supply; older ATX supplies only have one 12V rail.

You can beg, borrow or steal a PSU tester, or do a basic check of the power lines directly with a multimeter (every geek should have one). If you suspect the power supply, your best bet is to try another working PSU. Don't give up on a motherboard until you've tried it with another PSU first, or checked your PSU on another board.

Think carefully before using an old PSU with a new graphics card. Can it cope?

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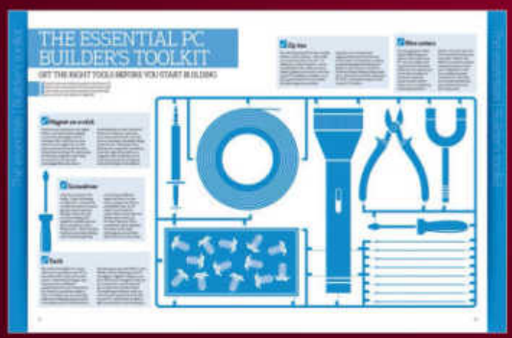

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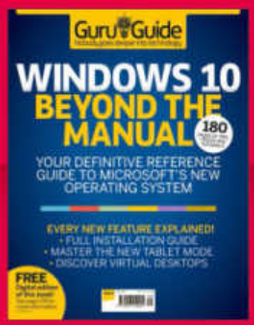

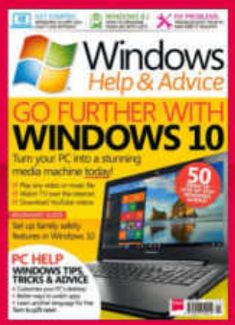

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